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Subsurface Buoy Forms for Array Applications

An Investigation

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SUMMARY

This is a review of the possible methods of constructing an apex buoy to be deployed as subsurface support for underwater pyramidal arrays. Several categories of buoy construction are presented, with an investigation of the mathematical expressions necessary to derive shape, size, weight, and net buoyancy. Selection of nominal probable buoy sizes based on studies done by others using the Navy-owned computer program "D-CEL" was made in the report development. Some cost data are summarized for buoyancy materials and devices available from commercial sources. Appendixes include spreadsheet calculations for various buoy shapes that lend themselves to construction as metal shell voids capable of operation at the selected water depth

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INTRODUCTION

The design of underwater array structures to instrument a three-dimensional volume of ocean waters will require, in all cases, some form of buoyancy to support the sensor systems in some desired posture away from the ocean floor. Buoyancy may be used in the form of a lighter-than-water construction of the array members themselves, or may be implemented as a surface float or as subsurface devices that would support all (centralized), as in figure 1, or part (distributed) of the submerged weight of an installed system. This document summarizes the categories of such flotation applications and reviews approaches to the implementation of flotation for array design.

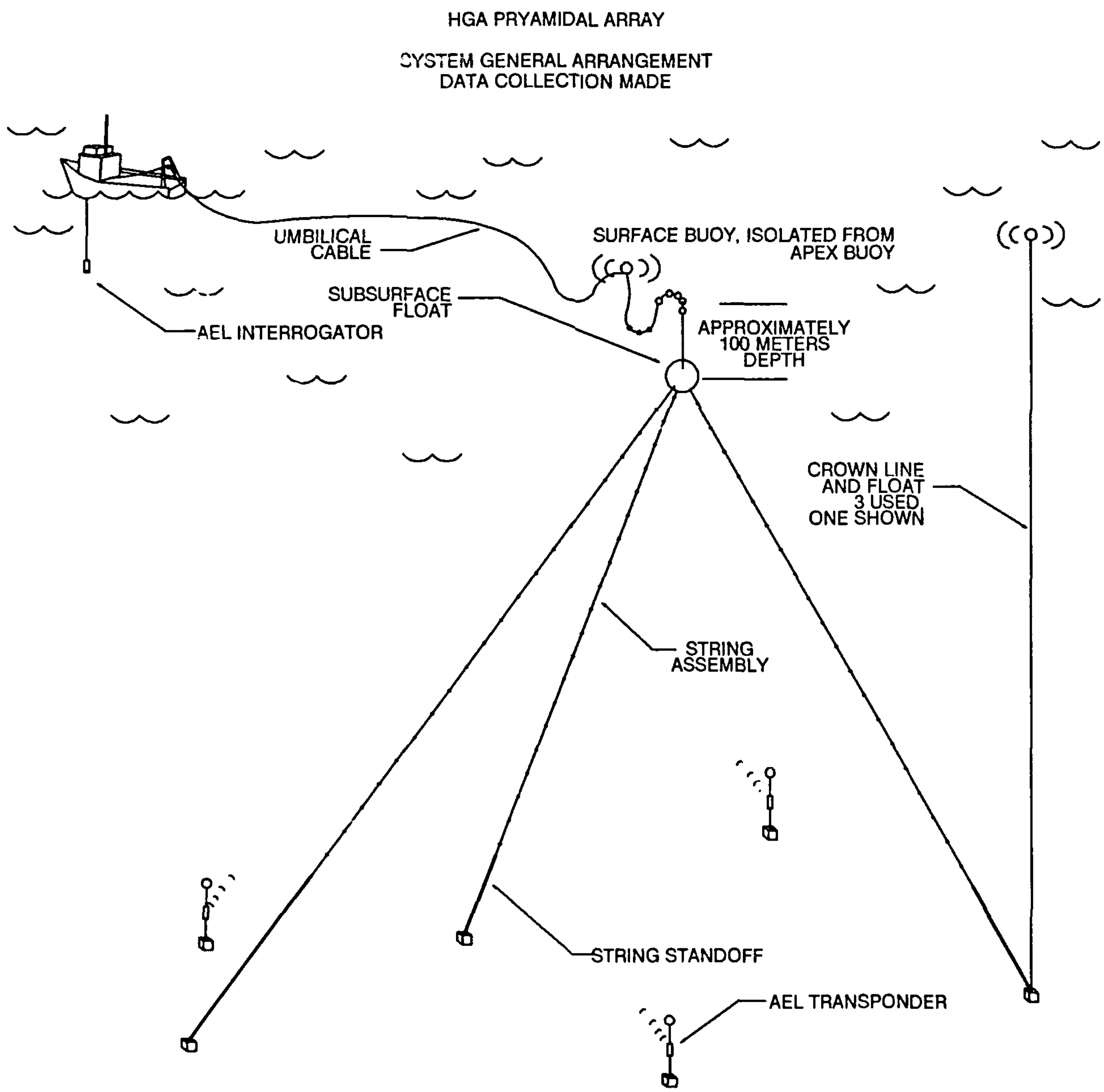


Figure 1. Pyramidal array postulated arrangement.

BACKGROUND

The High Gain Array Study Program has examined a variety of array systems and specific configurations that could be used in the pursuit of open ocean ambient volumetric noise measurement. Candidate configurations have ranged from a few vertical line arrays (VLA) to large fields of VLAs and to pyramidal configurations of three or more legs radiating downward from an apex supported by a subsurface float or suspended from a surface float. Surface float configurations discussed have ranged from surface buoys to surface platforms and even stable spar buoys.

For this review of buoy configuration opportunities, an array configuration and environmental circumstances have been presumed to be as follows:

- Water depth for installation, 5000 meters
- Current profile of 3 knots at the surface, tapering to 1 knot at 1000 meters, then to 0.2 knot at 4900 meters, and then falling to zero velocity at the bottom.
- Drag of the array leg configuration plus the apex buoy and accessories will produce an excursion maximum of 500 meters.
- The static depth of the apex buoy will be 100 meters.
- Maximum resultant design depth for the buoy (600 meters) is rounded off to 2000 feet versus 1968 feet (a concession to existing software configured to calculate in English units).

These parameters are presumed to be conservative relative to the environmental reality and will produce a range of component size and strength values capable of surviving the initial testing, which will be performed in the ocean environment. Engineering sensors installed in the pioneer test installations will provide precise information essential to tailor the hardware configuration specifications to the optimum needed to perform the assigned task. A projected pyramidal array installation is anticipated to resemble that depicted in figure 1. The range of dimensional relationships to be encountered in the design of a pyramidal array is shown in figure 2.

Materials available for the construction of the flotation devices include metals and synthetic rigid polymers, which can be used for the construction of watertight voids, to inflated and/or filled shells and lighter-than-water synthetics.

REQUIREMENTS

In general, flotation requirements vary with the class of application. The applications may vary over the entire spectrum of Ocean Engineering activities. The focus of this paper will be on the topic of tailoring a subsurface buoy to the task of supporting the apex of a three-leg pyramidal array. The array construction will support and locate, in three dimensional space, a family of sensors for the measurement of open ocean-basin data of interest. In particular, any choice of flotation must be

- Efficient, providing ample buoyant force with a minimum of weight, cost, handling difficulty, and corrosion susceptibility.
- Durable, capable of surviving the gamut of conditions associated with a complete service life, including outdoor storage prior to installation, assembly, and ocean installation wear and tear, in-situ wear and corrosion, recovery stresses and abuse, cleaning and refinishing, and additional prolonged outdoor storage.

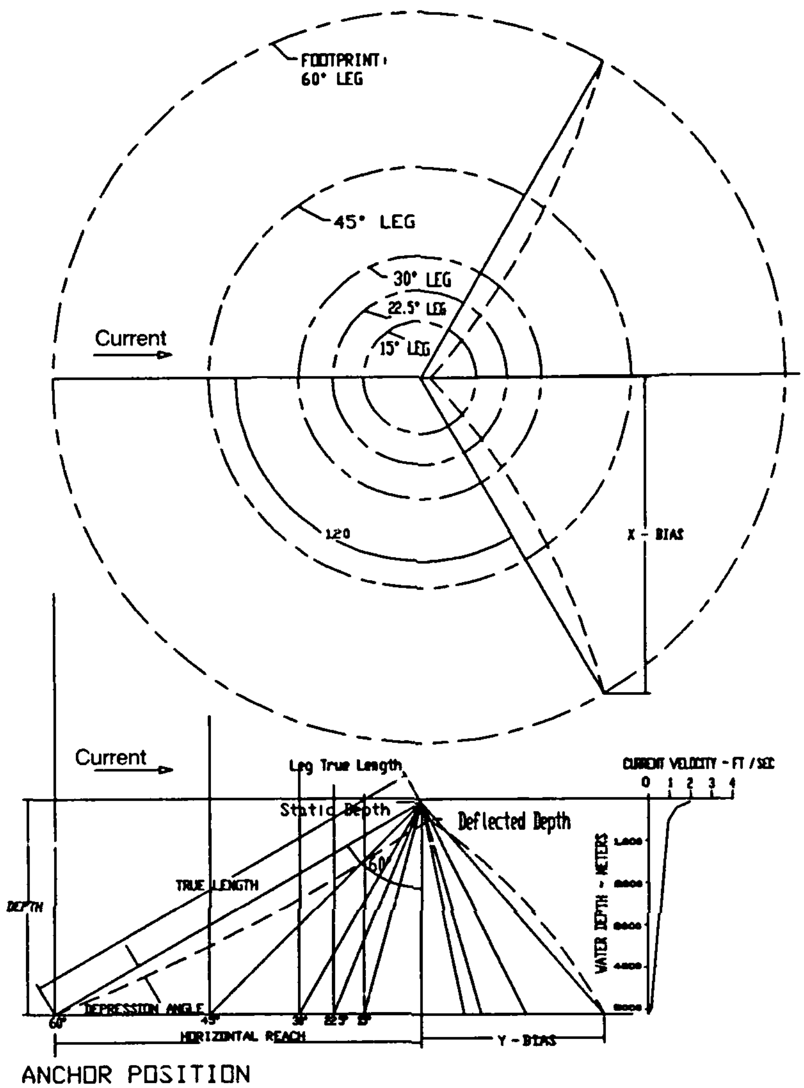


Figure 2. Pyramidal array dimensional relationships.

- Accommodate the functional requirements, provide connection and support for the attached array components, exhibit minimal drag properties in prevailing ocean currents, and respond to drag forces and changes of drag direction with a controllable and minimal change of attitude.
- Retain all the incorporated characteristics throughout the service life, especially be resistant or impervious to corrosion deterioration, wear and water absorption.
- Be reusable. It is anticipated that array design concepts will evolve over a number of years of testing and theoretical evaluation. Reusable components to support the ocean engineering aspects of that evolution are essential to the ongoing nature of the long-term goal.

Fundamental components of an array structure, such as the buoyancy devices, should be designed to be refurbishable and capable of being redeployed a nearly indefinite number of times. Of particular interest to the goals of the array data quality is the presence or relative absence of artificially generated noises, such as mechanical noise produced by articulating joints, flow noise from the passing of currents, and electromagnetic noise emanating from the installed devices or interconnecting cables and so on.

SYSTEM CLASSIFICATION

Two classes of flotation systems are identified.

- Buoy—either surface or subsurface, designed to support the total underwater weight of the attached load or system.

- Flotation—is any lighter-than-water object or material attached to a structure or object of interest to offset or mitigate the apparent weight of that structure in water.

The mass of the flotation material is additive to the mass of the host structure. The flotation will be carried to whatever depth the structure is deployed or experiences during the deployment evolution.

This report principally addresses the topic of buoy shapes and their derivation and does not consider the particulars of incremental flotation attachment in the construction or fine adjustment of array systems, even though the fundamental principals of design and construction of flotation devices will follow the same parameters of material selection and calculation of properties as for buoy construction.

CONSTRUCTION

MATERIALS

The full range of engineering materials can be embraced by the design of buoy and buoyancy components in array applications. The possibilities range from structural metals in mill and cast variants to glass. ceramics, and plastics. Fiber-reinforced plastic construction has a wide variety of reinforcements to choose from. These design opportunities are categorized and briefly described below. The full range of possibilities has not been covered, only the obvious candidates to satisfy the need of subsurface buoys and attached subsurface flotation tasks.

Formed Metal Plate Shell

Conventional unstiffened pressure vessel construction of dished plates edge-joined by welding is commonly used. Forming of half shells or smaller compound contours is accomplished by rolling, spinning, stretching, or pressing the sheet or plate materials. A sphere, for example, is commonly formed of 12 pentagonal dishes, which neatly join to describe a complete closed spherical shell. The process uses conventional industrial techniques, which readily support the cutting, forming, and joining functions needed to fabricate shell pressure vessels to the required thicknesses. Metals that can be considered include aluminum, mild steel, high strength alloy steels, stainless steels, and titanium. Hot and cold forming techniques are usable. Welded joints would normally be used in buoy fabrication. Heat treatment of fabricated shapes is applied for relief of fabrication stresses and realization of the full strength of parent and weld filler alloys.

Laminated or Filament Wound Glass Fiber and Composite Fiber

A shell bonded by suitable resins (pressure vessel) can be used to produce noncorroding pressure vessels suitable for use as surface and subsurface buoys, according to the strength of construction. The finished product would be noncorrosive and capable of long immersion in seawater. Lamination processes will produce shells of uniform strength and good surface finish and thickness accuracy if the layup (or sprayup) use female tooling and cures are done under pressure provided by an internal pneumatic or hydraulic bladder. One or more large openings must be left in the shell to allow removal of the bladder and associated fittings. Filament winding can be accomplished only through the use of specialized mandrel winding machines, which wind single or ribbon filament in a programmed helix around the mandrel. Catalyzed resin is wiped or sprayed at the point of contact of fibers with the mandrel, and the cure process is started immediately by heat or infrared light application.

Lighter-Than-Water Solid Filled Shell

Construction using a fabricated lightweight metal or molded plastic shell and filling the internal void with a low density material such as syntactic foam is possible. Construction of a thin-wall shell of engineering materials can provide resistance to minor impact and abrasion damage, can support hard points for attachment of various loads, and can afford the lightest possible structural arrangement. Filling the internal volume of such a structure with a buoyant and pressure-tolerant material will result in durable and lightweight assembly capable of supporting the imposed loads of an array leg system.

Gas-Filled Shapes, Pontoons, Bladders

Considerable study and testing has been conducted in the area of pontoons for salvage tasks to provide buoyancy as needed to refloat sunken structures, vessels, etc. Gas to fill the pontoons has been provided by precharged storage bottles. In some cases, tests have used gas produced on the spot by controlled chemical reaction of substances contained in storage vessels built into the test structure. For systems required to make large excursions of depth between the initialization of

filling (with gas) and the final location within the water column, a means of bleeding away an expanding gas volume or augmenting a shrinking bubble volume in proportion to changes of depth is essential. Additionally, loss of gas volume at a static depth due to leakage or dissolution must be compensated for in applications, which must achieve and retain a stable condition for an extended period of time. Tolerance of the system to brief depth excursions is poor and would require some innovative engineering to maintain sufficient volume in the event of a depth excursion, then bleed off the excess upon rising to the intended static depth. The technique does not seem to be very practical or cost-effective for the purpose of providing long-term support for array applications.

Fluid-Filled Shapes and Bladders

In several operations within memory, the operators resorted to the practice to use "Seal Bin" fuel transport bladders in sizes of 50 or 500 gallons as a container for buoyant fluids to achieve support of underwater devices that are to be recalled. The most convenient medium to achieve buoyancy in deep water has ordinarily been ship's diesel fuel. However, petroleum products are no longer acceptable for use in the oceans, and a more ecologically acceptable medium would have to be identified. The possibilities for the use of fluids as a buoyancy medium in conjunction with an array design is quite viable. A fabricated metal shell lined with a fluid-tight cell of fabric and sealant could be very competitive with more traditional approaches in both cost and size-weight efficiency. Elsewhere in this document it is shown that 155.52 cubic feet of buoy will displace 10,000 pounds of seawater. Net buoyancy is found by subtracting the weight of a 155.52-pound shape from the 10,000-pound value. A corresponding column of values is included in table 1, representing theoretical lift that does not include a container.

Some liquids with a density less than water are: (Weast, et al., 1990).

Glass Ball Floats With Hard Hat

Glass floats are commercially available in two sizes: 10-inch diameter and 17-inch diameter providing buoyancy values in salt water of 10 pounds and 56 pounds of net buoyancy, respectively. Hard hats molded of high-impact polyethylene sheet are available in four configurations to protect the globes from impact and abrasion damage and at the same time provide a purchase for mounting the floats to a structure, figure 3. The floats are constructed to a depth rating of 6700 meters (22,000 feet). The floats can be fitted with functional penetrators with perforation diameter ranging between 0.25 to 0.75 inch for power and signal activities to enable their volume to be additionally used as a pressure housing for instrumentation as might be needed by the project task.

Table 1. Density and lift properties for selected light fluids.

Compound Name	Specific Gravity	Weight lb/ft	Buoyancy lb/ft	Lift per 500 gal	Lift from 155 ft^3
a. Acetone	0.792	49.4	14.6	976 lb	2271 lb
b. Ethyl alcohol	0.791	49.4	14.6	1002	2331
c. Benzine	0.85	54.9	9.4	628	1461
d. Gasoline	0.66	42.5	21.8	1457	3390
e. Kerosene	0.78	50.2	14.1	942	2192
f. Crude oil	0.83	53.1	11.2	749	1743
g. Diesel fuel	0.80	51.4	12.9	862	2006
h. Naphtha	0.67	41.5	22.5	1503	3497

* Value shown is the buoyancy for the liquid alone. The weight of the container is not included.

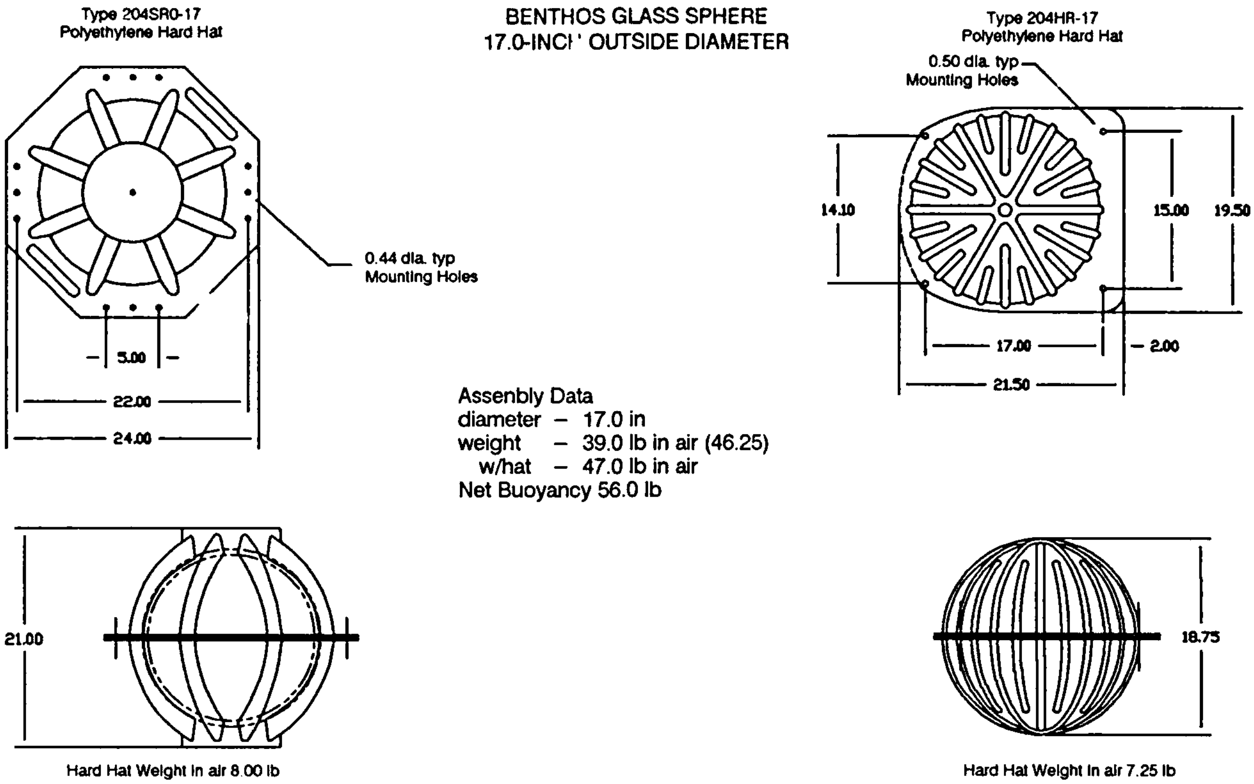


Figure 3. Two hard hat configurations available for array construction applications.

FABRICATED SHAPES

Several conventional shapes could be considered as surface or subsurface buoys, including the followi ıg:

Cylinder, Right Circular

With an aspect ratio (length to diameter) L:D of 1:1 as the family illustrated in figure 4.

With Flat Plate Ends

A simple shape, easily fabricated, but requires substantial material thickness to achieve adequate strength in the end bungs, so substantial that a design for 2000-foot depth is negatively buoyant. Drag characteristics in the water currents are higher than the other candidate shapes, with the probable exception of assembled shapes, which use no fairing to smooth water flow.

With Hemispherical End Bells

Substituting hemispherical ends on a cylindrical buoy shape, which was to have a 1:1 length to diameter ratio, does not leave much cylinder when the original diameter and volume parameters are held constant. However, the use of the hemispherical end bells yields the greatest efficiency as a pressure vessel, thus requiring the thinnest material.

With Semielliptical End Bells

For use in pressure vessels, semielliptical end bells are ordinarily implemented at a 2:1 ratio of major radius to height, in accordance with Civil Codes. On the other hand, optimization of the drag coefficient to the best possible value is strongly desired. The elliptical shape with a width to height ratio of 1:1.8 yields a coefficient of 0.07 versus the value for a sphere of 0.20. Unfortunately, corresponding values for the range of possible shape variants are not readily available. Realization of the computed strength values is very dependent upon accurate reproduction of the

constantly varying radius of the bell from flange to top of the crown. Abrupt changes of radius resulting from marginal control of the forming device will produce stress risers and consequent failure points not consistent with the calculated properties.

With Torospherical End Bells

Also called "dished and flanged," this configuration is somewhat shorter than the semielliptical end bell arrangement, but the shape is not recommended in the Civil Codes for pressure regimes greater than 150 psi (Bednar, 1981). Any design intended for use at depths greater than the corresponding 335 feet would require the development of prototypes to be methodically tested for a full understanding of properties. At operational conditions less than that value, the stress equations computations show that the thickness of the head is nearly identical to the sidewall thickness for the cylindrical body. As with the elliptical form (actually oblate spheroidal) described above, sensitivity of the form to poor adherence to prescribed contours and superficial damage is pronounced. The proportions of the torospherical construction can vary widely, ranging from a full sphere to a flat plate with no included void at all. Tolerance of the shape to deep water pressures also varies widely.

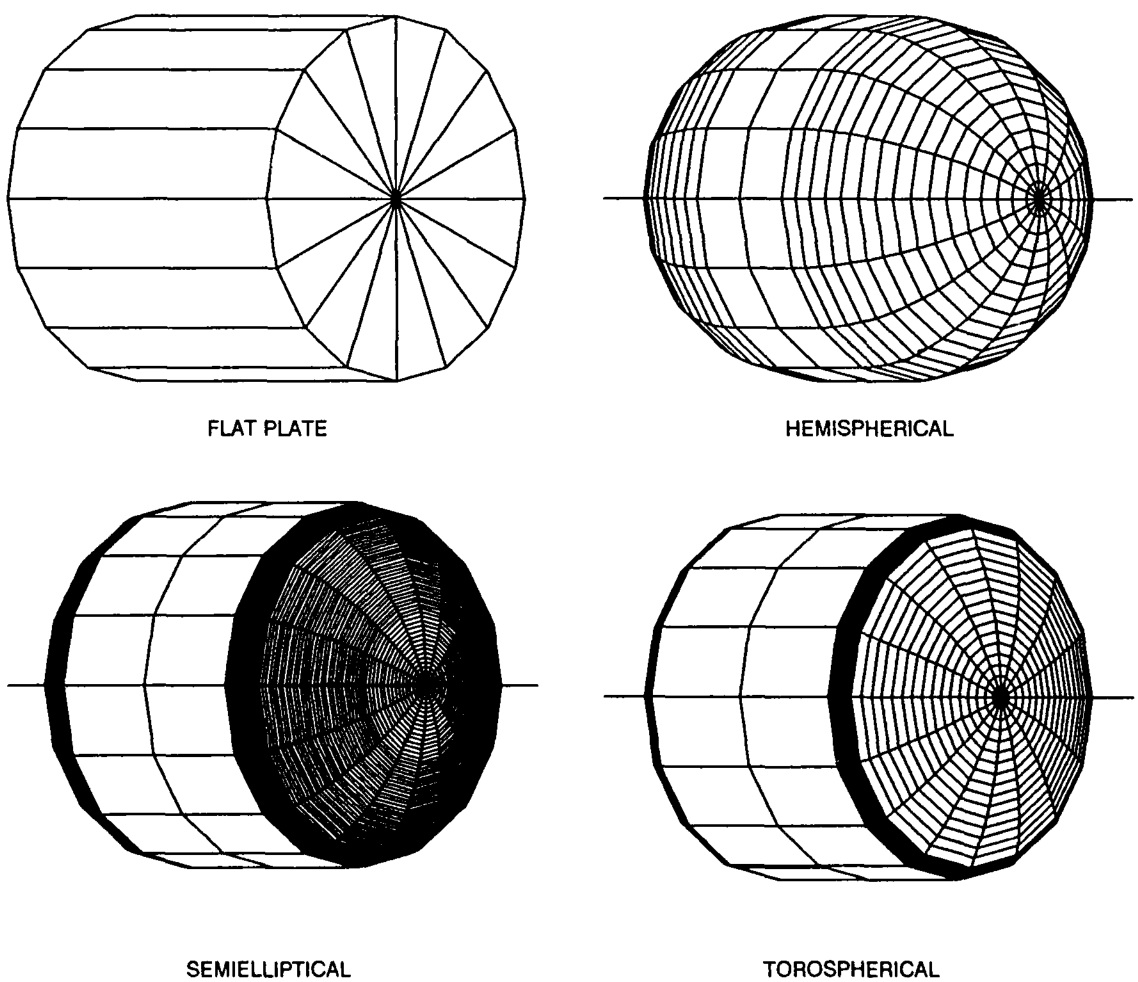


Figure 4. Family of cylindrical buoys with various end closures, all displacing 10,000 pounds with a diameter of 70 inches.

Nest of Cylinders with Fairing

This variation, shown in figure 5, is intended to imitate the characteristics of the simple cylindrical shape, except that it uses three (the number would be equivalent to the installed number of array legs) individual cylinders each displacing one-third of the volume of the single-piece buoy. The length to diameter relationship of the outer fairing is held at a 1:1 ratio. Therefore each individual buoy, attached to its own array leg, has an aspect ratio of 2.15:1. The assembled buoys with fairing are 1.15 times the size of a simple cylindrical buoy.

Sphere

The most efficient shape for the weight of material used and the smallest representation of the displaced volume of seawater. The compound curved exterior plates are fairly difficult to fabricate and weld watertight when compared to the single-curved contours of the cylinder. Stress distributions are complicated when the shell is interrupted to incorporate features such as an internal void. Many such structures cannot be calculated by formulae in the ordinary literature, and prototype structures would require proof-testing to validate the service structure.

Ellipsoid

Not a true ellipsoid, but an oblate spheroid generated by the revolution of an ellipse about the minor axis. This shape is the most efficient with respect to form drag in the water currents at an aspect ratio of diameter:height = 1.8:1 (Meyers, Holm, and McAllister, 1969). Structure is similar to that of the sphere, but the oblate shape forces a need for additional material to provide adequate strength, a characteristic that increases with the reduction in height. Incorporation of voids to house accessories such as junction boxes, location devices, and so on, imposes similar considerations to that of the sphere construction. In addition, buoy manufacturers indicate that the accurate forming of the elliptical shape is especially difficult. Only minor deviation from the true elliptical form will invalidate the stress calculations.

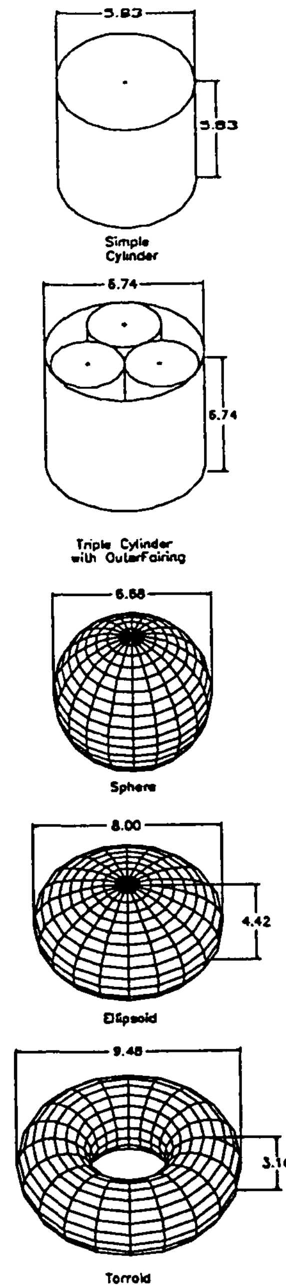


Figure 5. Generic buoy shapes; dimensions for 10,000-pound displacement.

Torroid

The attractive features of the torroid form are twofold: first, the shape allows the lowering of hardware for support of adjunct activities through

the center opening, and second, the centroid of the shape exists outside of the structural voids, allowing the suspended hardware attachment point to be made at the physical centroid of the buoy (figure 6). This configuration then eliminates pitch motions of the buoy relative to the attached array cables. Thus, bending or flexure of the connection point is controllable. All other buoy configurations require accommodation of considerable flexure at the attachment point. The negative aspect of the torroid approach lies in the difficulty of forming the smooth compound curved shapes needed to realize the calculated properties. Drag properties for the shape are approximately three times greater than that for the spherical shape of the same volume. The drag penalty can be considerably improved by the addition of fairings to the top and bottom of the shape to emulate the drag profile of the ellipsoidal (really torospherical) form. By inspection, this stratagem would complicate the realization of the benefits outlined above, but attachments to the centroid of the shape that would pass through the fairing surface can be accommodated by slots sealed by elastomer lips that close around the penetration. Special testing would probably be required to optimize the shape and establish the true coefficient of drag and related parameters.

Torospherical

Similar in appearance to the ellipsoidal form, the torosphere is defined by two radii: the smaller radius establishing the edge contour, and a larger radius to bound the crown portions of the shape. Drag characteristics are similar to but slightly higher than the elliptical form for corresponding aspect ratio of diameter to height. The two shapes are shown in comparison in figure 6. The torosphere is proportioned at the same height-to-diameter ratio of 1:1.8, and the flange radius is one-sixth of the diameter.

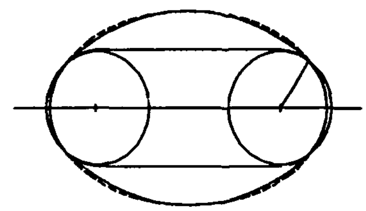


Figure 6. Relationship of elliptical (dashed) to torospherical construction.

Assembled Shapes

Assemblies allow the use of the most cost-effective buoy shapes while retaining the ability to use the most convenient configuration, but at the expense of additional weight and bulk in the total assembly. A plausible general configuration for a complex buoy assembly is shown by figure 7. Note that the line radiating downward (and upward, stowed) in figure 8 represents the centerline of a pivoting link which provides an attachment for the supported array leg and is arranged to effectively pass through the centroid of the shape, thus imitating the attractive characteristic of the torroidal shape. Finally, the upward or stowed position of the link centerline shows that the attachment point can be elevated above the water line of the buoy resting on the surface, allowing access to the connection point of an array component. This feature enables compatibility of the buoy with the more complex array installation schemes discussed by others. Additionally, more displacement modules may be added to the assembly in the event that the physical parameters of the array evolve to a new configuration requirement, such as additional quantity of array legs, additional weight, or drag per array leg, etc.

Other configurations of a compound buoy are of course possible, limited only by the engineering imagination applied to the task and to special performance problems to be addressed in the candidate design. None of these potential variations will be addressed in this report.

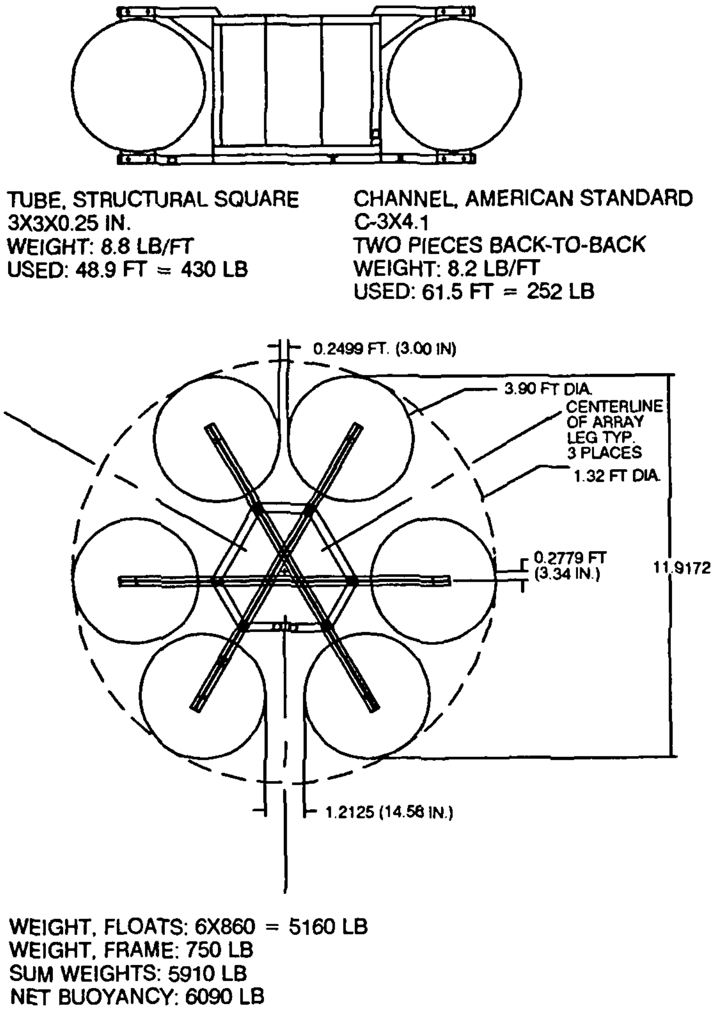


Figure 7. General arrangement of a compound buoy assembly capable of providing 6000 pounds of net buoyancy.

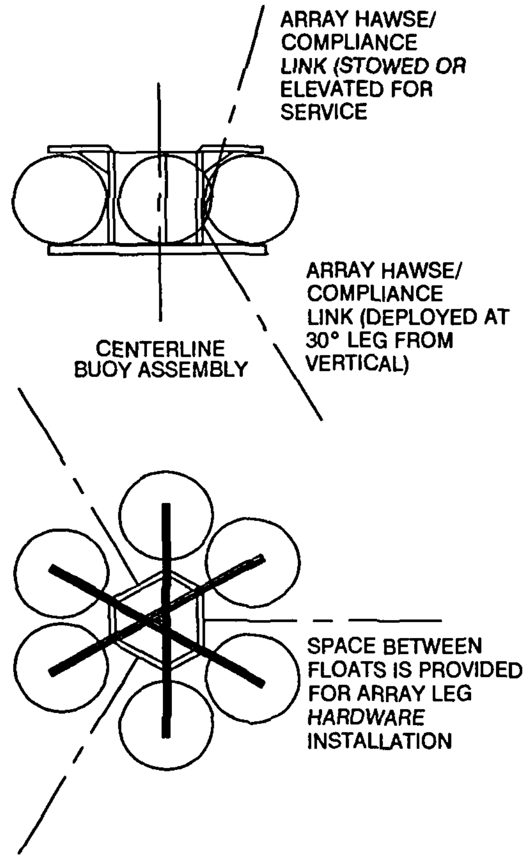


Figure 8. A practical approach to the configuration of a compound buoy structure.

CHARACTERISTICS

The following paragraphs are specifically directed to the array configuration consisting of three or more array legs deployed pyramidally from an apex which, in turn, is supported by a single source of buoyancy, i.e., a subsurface buoy. The entire weight of the assembled array legs and their companion hardware is supported by the buoy, the system tension is established by the reserve buoyancy of the structure, and the tension, in turn, will determine the positional stability in response to ambient water column currents of the upper regime of the complete array. By inspection, the suspension of ropes from a buoy seems quite straightforward, but a number of issues must be addressed. In particular, how much buoyancy is required to provide adequate support and tension for stability? If the array legs are constructed to be either positive or negative in their individual inherent buoyancy, the catenary developed will be correspondingly shaped. The degree of that contour, all other influences being fixed, will be a direct function of the leg tension imposed by the buoy's excess buoyancy. Similarly, if the array legs are constructed to be precisely neutrally buoyant, each leg will follow a straight line contour as imposed by the tension component of excess buoyancy between the array apex and the anchor point. The influence of current drag upon the disposition of the array legs will be to billow toward the downstream direction of current flow. Correspondingly, if the leg construction is of positive or negative buoyancy, the static disposition will be convex or concave accordingly, the degree of contour in proportion to the resultant vertical force component of weight or buoyancy.

SUBSURFACE BUOY CONFIGURATIONS

A Single Buoy

Supporting the hardware by a common attachment point at a pyramidal array apex will be held more or less in a fixed location in three dimensional space as a function of the angle of departure of the attached constraints (array legs), as in figure 1. The positional fixity of the buoy would vary widely with the amount of reserve buoyancy and the array leg properties—especially if the in-water characteristic produces a positive convex catenary or negative concave catenary shape.

Compound Buoy

This approach, suggested in figure 8, would consist of several individual buoys within a structure functioning as a single buoy, but offer a different set of advantages and associated disadvantages. Such a construction would be implemented as a structural frame supporting several floats. The framework would accommodate all structural loads, including the buoyant forces and the weight of attached objects such as the array legs, component junction box, umbilical cable tether, mooring accessories, surface marker buoy, and such appurtenances. The advantage seen is twofold. First, damage or leakage experienced by one of the several floats would alter the performance of the buoy but not be an immediate cause for loss of the buoy and, therefore, the whole array. Second, the physical arrangement of all the components and attachment points can be controlled more than any other approach. The introduction of loads to the structure can be arranged for the minimum attitude reaction to variances in current drag forces as well. The negative features include increased drag due to a complex shape, greater weight for the amount of buoyant force provided, introduction of mechanical and form noise to the array environment, and greater susceptibility to corrosion related failure.

Separable Assembly of Buoys

One float to each array leg mechanically joined and functioning as a single buoy in situ, but capable of separating into individual leg buoys at the time of recovery, offers the greatest possible simplification opportunity to the recovery evolution scenario (figure 9). This case is attractive in that, as mentioned, the task of recovery is

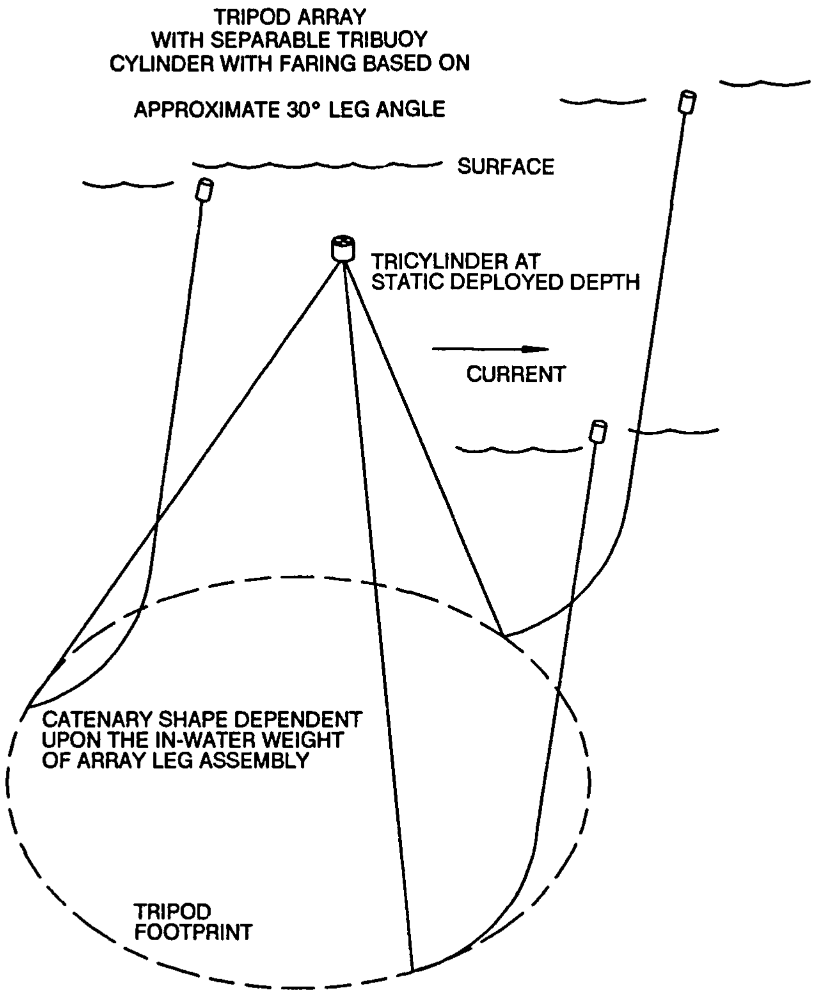


Figure 9. General arrangement, tripod array using a three-part separable subsurface apex buoy.

enhanced, plus the multiplicity of floats provides safety in the event of a single float failure. Flooding of one of the three floats will not necessarily result in the immediate loss of the array or of the affected leg until recovery, although the stability of the array resulting from reduced leg tension will certainly be reduced. Operational complications will obviously arise if a recovery evolution is attempted, unless the condition is detected and a means of attaching supplemental flotation or a retrieval line to the affected leg can be accomplished. But, that is all in a day's ocean engineering work.

LOAD REQUIREMENT

The load to be supported by the subsurface buoy structure includes both static and dynamic burden sources. The obvious load sources include: in-water weight of attached array components, umbilical cable, riser to surface marker, instrumentation packages or suspended strings, attached system junction box, and accessories such as location beacon devices. Less obvious burden sources include accumulation of marine growth, fouling by flotsam, and fouling by objects from the surface, such as fishing nets. The final category of

burden consists of dynamic loads experienced during service and during the deployment retrieval sequences of events. These primarily associated with accelerations seen in dropping and experiencing sudden stops. Drag resulting from the passing of ocean currents are readily calculated given the velocity, properties of the water column, and coefficient of drag for the collection of shapes to be included. However, the effects produced by the distribution of drag forces on the parts and upon the whole is complex and everchanging. Investigation of array static forces and displacements can be supported by modeling through the use of appropriate computer programs such as D-CEL. The coding for the algorithms of moored object analysis has been obtained by Naval Ocean Systems Center (NOSC) from the Naval Civil Engineering Laboratory and are presently installed and operable on the NOSC Stingray computer system. Much more study of the array responses to current will be needed before a serious system design can be completed.

DEPTH REQUIREMENT

By intuition, the depth requirement of a subsurface buoy is equal to the intended depth of the apex of the pyramid configuration. However, additional factors must be considered in the establishment of the structural depth requirement. First, of course, is the intended apex depth, and second, is a short-term depth excursion promoted by the dynamic forces of deployment and of recovery evolutions. Also, there are transitions in depth seen in service associated with the accommodation of current drag by the assembly as a whole. In the pyramidal array, static tension of the array legs is provided by the reserve buoyancy of the subsurface float. Lateral forces imposed by current drag upon the attached components will result, once the static restoring force is overcome, in displacement of the subsurface buoy. Since the buoy is effectively restrained by one or two anchors through the array legs (depending upon the orientation of the disturbing current), the system will pivot about the line of restraint until a new position of system equilibrium is achieved. The pivoting of the assembly about the nominal anchor position will produce both horizontal and vertical movement of the apex buoy in three-dimensional space. The vertical component will be seen as a depth excursion of the buoy. The depth (pressure resisting) capability of the buoy must be better than the sum of the static depth of the design plus the greatest possible excursion to be produced by the most severe current to be seen in service, as well as the temporary but significant depth excursions imposed by the installation and handling activities. As shown in figure 10, in addition to these observations, the array legs will develop a catenary shape due to the distributed force of current drag along the entire length of each of the members. The nature and extent of the developed catenary can be deduced from the calculations output by the D-CEL runs.

FUNCTIONS PERFORMED

In the situation of deployment that calls for the installation of temporary buoyancy to a hardware assemblage as an aid to the deployment process, an inflated flexible float that will collapse with depth is an option. A delayed release in the form of a corroding attachment link can be incorporated to rid the final installation of the drag and other encumbrances of a now-useless appendage.

ACCESSORIES TO BE ACCOMMODATED

Accessories include all and every attachment to the subsurface buoy in the assembly, except the array leg assemblages proper. Instrumentation strings separately attached to the buoy, individual instruments, marker beacons (including acoustic pinger and/or transponder, flashing lamp, or RF beacon), electronic junction box, riser to a marker buoy, or umbilical cable to the outside world may be accommodated. Interface hardware between the array legs and buoy foundations such as shock mitigation modules (sometimes labeled "compliance modules") might be incorporated into the assembly, although these would be considered part of the array burden proper.

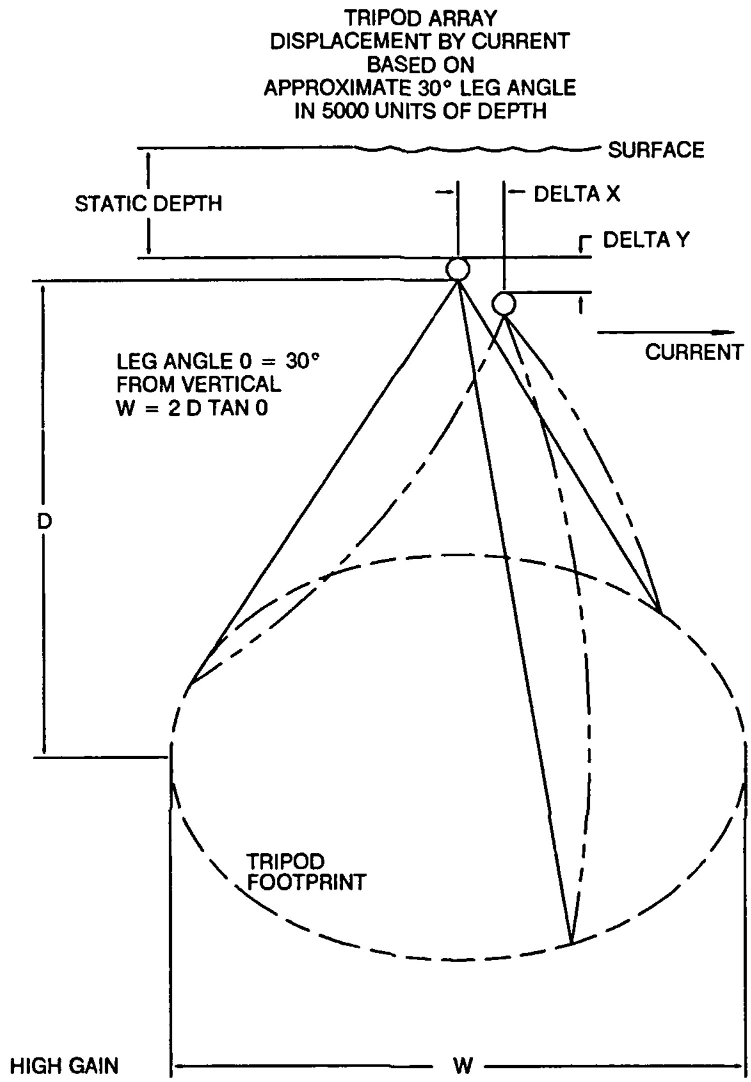


Figure 10. Influence of current upon buoy depth and altitude.

BUOY/ARRAY ATTACHMENT GEOMETRY

Consideration should be given to the nature of the physical attachment of the array leg load to the subsurface buoy. In general, forces applied to the buoy that do not pass along a line radiating from the center-of-form will produce a couple in combination with each other and with the center of buoyancy. The resultant of these forces will produce a pitch response in the buoy as it restores itself to a posture of equilibrium following any external disturbance. In that the disturbing force produced by changing currents is dynamic and everchanging, the buoy will exhibit constant pitch motions accordingly.

The design of the load attachment points should consider these behaviors. Two paths of accommodation are available: first, to design the attachment points to automatically radiate from the centroid of the assembly, and second, to design the connecting points to accommodate and tolerate significant relative motion for a prolonged period of time, well in excess of the planned tenure of the array system in the operational installation. The design of attachment points to support the intended load in the optimum geometry must consider the angle of departure of the leg from the buoy. However, the angle of departure can vary markedly from the nominal angle of the array leg between the buoy and the respective anchor depending upon the net tension of the leg and upon the inherent buoyancy of the leg assembly in water. If the leg were constructed to be precisely neutral throughout its length, the attitude of the leg with respect to the buoy/anchor would be a straight line in a static no-current condition.

Obviously, there will be few occasions when the no-current and, thus, straight line condition will exist. Each current condition will cause the leg assembly to billow or depress with respect to the location of the array apex. If the array leg design were to be positively buoyant, the motions at the buoy connection point would vary between billow and less billow. A negative angle of departure (tending upward from the horizontal) could be experienced. Conversely, strongly negative buoyant leg assemblies could depart the buoy nearly straight down allowing the buoy and its attachment points to behave as though there were a single riser and, thus, approach a condition of no relative motion of the legs to the buoy attitude.

Although this report addresses only three-leg pyramidal array construction as an end use for the subsurface buoy, there are many other possible approaches to the construction of complex underwater structures, interconnected by cables and supported by subsurface buoy assemblies (Berteaux and Walden, 1981). Such studies show that array configurations other than a multileg pyramid tend to be less stable in the environment of volumetric water movement. As the number of legs in a pyramidal arrangement is increased, however, there is a recognizable improvement in the stability of the pyramid apex position. Distortion of the individual legs does not remain a direct function of the drag profile, frontal area, line tension, and disturbing current gradient.

CRITERIA FOR SELECTION

The following topics are, in large part, a function of the ambitions of the acoustic design and performance goals of the array system. As such, they are beyond the scope of this paper, but some reflection of the influence of each is in order.

WATER DEPTH FOR ARRAY

The bottom depth of the installation site will determine the length and, therefore, the mass and drag load surface area of the lines attached to the apex buoy. Even if only a small portion of the total water depth is to be instrumented, the mooring line length necessary to reach to the anchor locations will contribute a major set of forces for the subsurface buoy to support.

ARRAY LEG INCLINATION ANGLE

For a fully submerged pyramidal array geometry of three or more regularly spaced legs, the array leg included angle could vary from nearly upright to practically horizontal. Of course, there are some practical limits between these extremes. Small included angles allow the lateral force components, which establish position and stability, to also be small. The greater the leg separation, within reason, the more stable the pyramidal shape will become. On the small side of the scale, the values to be considered depend upon the water depth and the ratio between the depth and the static depth of the installed subsurface buoy. The smallest practical leg angle is that included angle that will just allow the buoy to remain at the surface after the second anchor is positioned. This angle works out to be on the order of 18 degrees away from the vertical. Real-world practice will invariably add a complication to the installation in the form of surface currents, which will stream the first two legs with the buoy attached with sufficient developed force to carry the buoy under the water surface. In these circumstances, makeup of the third leg and other final hardware to the buoy would be severely impeded. Therefore, the real smallest angle to use for a straightforward installation sequence would be approximately 23 degrees. However, a more complex installation scenario, which allows the second leg to be initially set close to the first (allowing hookup of the third leg) then relocated to the desired position as a final maneuver, can be used to incorporate an otherwise unmanageable geometry, allowing an included angle as small as 15 degrees. On the other hand, the largest doable leg angle geometry is probably only limited by how much array leg and mooring line can be laid out on the surface between the buoy (still afloat) and the anchor lowering location, or by how well the surface vessel can navigate to the specified locations. It should be observed, though, that very long array leg assemblies, which are negatively buoyant, will develop a large catenary between the anchor and the attachment point at the supporting buoy while the buoy lies on the surface. This kind of temporary geometry will certainly serve to complicate the installation and adjustment procedures. Depending upon depth, the greatest practical angle lies in the realm of 70 degrees. The farther apart the array anchors are, the larger the proportion of the buoy lift realized as a horizontal vector and how little remains as a vertical force. The result of this extreme condition is that a given disturbing current will produce increasing vertical excursion in the buoy in achieving equilibrium. It has been stated that the most stable positional geometry is realized at an angle of about 50 degrees.

SUBSURFACE BUOY STATIC DEPTH

The first guideline establishing the depth of the subsurface buoy in a pyramidal array installation would be the planned depth of the topmost sensor to be supported by the buoy. Additionally, environmental considerations should be incorporated whenever the technical requirements would allow. First, currents are ordinarily greatest near the surface, tapering to minimal values at around 500 meters depth. Second, local orbital water motions produced by surface wave forms can have an effect at depths to about 200 meters, depending upon the period and length of the wave pattern.

Third, biological activity in the water column varies in accordance with temperature, oxygen and nutrient content, and ambient light intensity. The greater the depth the buoy can occupy, the less the accumulated burden of biological fouling to be accumulated during the tenure of the system installation. As a rule, growth is negligible or nonexistent for the first 6 weeks of immersion until the foundation of slime colonies are established. Once the foundation exists, though, both plant and animal families will soon become prominent. As an example of the impact of biological fouling, an experiment using a number of molded plastic floats to support an instrumentation framework (admittedly a platform with a large surface area) was ballasted to leave 50% of the float surfaces above water. Sufficient growth was accumulated in 6 to 7 months to sink the assembly.

TENSION REQUIREMENT

The tension to be established in a given array leg shall be designed to achieve the desired (or best possible, whichever is less) static and dynamic positioning of the apex of the array. Horizontal and vertical excursions of the subsurface buoy in response to disturbing currents for a given geometry can only be controlled through adjustment of the reserve buoyancy of the supporting buoy. The greater the excess buoyancy, the larger the array leg individual tensions and, thus, the greater the horizontal vector components that radiate equally away from the apex to establish a stable (static) position in the water column. Horizontal displacement of the apex should not commence until the sum of the vectors in the direction of the current becomes greater than the resisting vectors. More or less tension in the leg assemblies can be required to satisfy the particular objectives of the instrumentation carried, i.e., measure the effects of current on the geometry, or to minimize the catenary developed by a leg system that cannot be made any more buoyant.

CURRENT PROFILE

Thorough knowledge of the water current activities of the vicinity of the installation site is crucial to achieving predictable behavior of the array system. Several kinds of current behaviors might be encountered.

General Volumetric Flow

In a fixed geographic direction, graduating from a high value at the surface to a negligible condition at the bottom. The most significant changes will occur within the top 500 to 1000 meters of depth.

Variation of Current Direction

With depth can occur, exhibiting either gradual change or instantaneous change (shear layers). Turbulent patterns can be experienced if the installation location lies at or near the margin of opposing volumetric flow systems. Gyre activity can produce local whirlpools extending to depths of several thousand meters. As such, a system passes through an array structure, and very unpredictable responses may occur.

DRAG CHARACTERISTICS OF TOTAL SYSTEM

In the situation of deployment that calls for the installation of temporary buoyancy to a hardware assemblage as an aid to the deployment process, an inflated flexible float that will collapse with depth is an option. A delayed release in the form of a corroding attachment link can be incorporated to rid the final installation of the drag and other encumbrances of a now-useless appendage.

CALCULATION OF DEPTH EXCURSION OF BUOY

Drag forces acting upon the three array legs, the subsurface buoy, attached cabling, and mounted accessories will tend to displace the assemblage downstream. If the buoy is thus displaced by the horizontal force disturbance, it can only relocate by describing an arc about the fixed point of restraint. That point is the array leg attachment to the bottom anchor. The net response of the subsurface buoy is a motion downstream

and downward. The design buoy depth requirement is a resultant of these considerations. Array models processed with the D-CEL program have shown, among other things, that a change of reserve buoyancy of a few hundred pounds will be reflected in the static depth of the subsurface apex buoy on the order of tens of feet. Since this report does not incorporate the study of array behavior specifics, it is not possible to provide comprehensive insight to the real behavior of a suspended array system.

DETERMINATION OF REQUIRED NET BUOYANCY

A first investigation simplified spreadsheet has been developed by W. Macha, NOSC Code 942, to give a first estimate of net drag experienced by a line array deployed in the typical ocean basin. These calculations follow simplified but conventional techniques. Several texts (Berteaux, 1976) are available to review the development of calculations appropriate to the static equilibrium of mooring systems and arrayed cable behavior. To establish an accurate picture of buoy burden parameters, such calculations require a comprehensive knowledge of the environmental conditions to be experienced during the installation period. No accurate current data for the installation site nor even a specific candidate operating site have been confirmed for these initial calculations, hence a postulated current profile is used. These calculations show that the specific drag values for the apex buoy on an array leg length up to 10,000 meters long is less than 5 percent of the total drag seen by the assembly.

DATA

COMMERCIAL SOFTWARE

A commercial computer program, *Under Pressure*, Version 3.01 (DeepSea Power & Light Inc., 1989) has been used to assist in the performance of pressure vessel calculations for spherical and cylindrical shapes. The program mostly uses the expressions found in *Formulas for Stress and Strain* (Roark, 1989). Example calculation data produced by that program are given in appendix F.

CALCULATIONS FOR SPHERICAL BUOYS

Calculations have been made in a spreadsheet to determine the structural parameters of spherical buoys (thick shell, not a rib-stiffened structure) fabricated of hot rolled steel plate with an allowable yield stress of 24,000 psi. The calculated shapes included plain closed shells and shells with an internal wet void and hawse tube to accommodate an internal electronic junction box communicating to an opening at the bottom of the buoy for the passage of connecting cables from the array legs. A range of sizes of spheres beginning at a water displacement of 1,000 pounds and selected displacement sizes through 25,000 pounds were incorporated. Additional calculations depicting intermediate or larger sizes and variations on the void configuration can be readily generated.

CALCULATIONS FOR CYLINDRICAL AND OTHER BUOY FORMS

The spreadsheet for the calculation of structural parameters of cylindrical buoy shells is included in appendix A, along with supporting calculations from the Under Pressure Program. The model calculation of dimensions and parameters for the basic unit displacing 10,000 pounds of seawater is accompanied by calculations for buoy displacements ranging between 500 and 25,000 pounds. Likewise, spreadsheet calculations for the other candidate shapes, i.e., spherical, ellipsoidal, torospherical, dished and flanged, and torus have been prepared for inclusion in appendices B through D.

DATA FOR SYNTACTIC FOAM SYSTEMS

Many formulations and numerous configurations are available from the syntactic foam industry. These materials come in a wide range of specifications. For the uninitiated reader, syntactic foam describes a group of products using pressure-tolerant balloons of various materials bonded in a matrix of polymerizing resin. The balloons range from glass Microballoons® with the consistency of wheat flour, manufactured by Corning Glass Works and others, to Macroballoons® of Epoxy resin in sizes ranging to 2 inches in diameter. Depth tolerance for the various formulations ranges from about 2000 feet to at least 24,000 feet. The compounds may be mixed and cast at the job site, or may be purchased as factory produced blocks, usually 1 cubic foot in size. In addition, custom shapes may be ordered cast by the factory even to include a highly finished integral shell of fiberglass reinforced plastic.

Foam-Filled Fabricated Shell

A user-supplied metal or synthetic container/protective skin can be filled with a syntactic foam mixture prepared on the site and is an appropriate approach to vendor fabrication. Density and service depth expectation are competitive with premolded blocks produced with factory tooling and production control methods, although finish and uniformity of the final product is usually less than that possible with factory resources. The greatest probable topic of deficiency would be in the area of removal of entrapped air in the microballoon/resin mixture. This normally would be controlled through the selection of a slow catalyzing resin and purging the catalyzed materials in a vacuum chamber prior to curing, and by the maintenance of external mechanical pressure on the cast throughout the cure period. Thick cast sections can produce sufficient heat to result in internal fracturing of the block; therefore temperature control and aid in heat rejection may be required. See table 2 for specific information on the materials available for field-cast projects.

Foam Block Assembly with Fiberglass Laminate Shell.

Procured syntactic blocks assembled within and confined by a user-designed framework, then encapsulated by a laid-up Fiberglass and resin skin can be used to produce a float assembly to a specific net buoyancy value. Standard rectangular blocks may be used that will produce a rectangular final form, or the builder may resort to shaping precast blocks to fit into more convenient outlines such as a disc or pseudospherical or elliptical shape. The inclination to avoid shaping standard blocks through purchase of made-to-order contoured parts will incur the very substantial additional cost of custom tooling.

Framework Holding Precast Foam Blocks

Precast syntactic foam blocks are available in 1-cubic-foot rectangular shapes for a range of densities and service depths, table 3. Many configurations of resins, microballoons/macroballoons are produced. For a service depth of 2000 feet, formulation densities of between 26 and 32 pounds per cubic foot would apply. Foam formulations adequate for specific service depths can be obtained in the lightest possible configuration, i.e., precast blocks for 2000-foot service, which would have a density of around 24 pounds per cubic foot versus about 32 pounds per cubic foot for user-cast kit materials.

Integral Die-Molded Foam Disks with Laminate Shell

Vendor tooling exists for the fabrication of syntactic foam disks designed to become an assembly measuring 96 inches in diameter by 31 inches high. This assembly, illustrated in figure 12, displaces 125 cubic feet (8000 pounds of seawater) and weighs 3300 pounds, giving a net buoyancy of 4700 pounds. Manufacture of replicas of this product could be ordered at a cost saving because the tooling cost is previously amortized and only the handling cost of reinstalling the forms is reflected in the selling price.

Table 2. List of available syntactic foam kit materials for field-cast buoyancy systems.*

Product Type Number	Kit Vol ft³	Buoy-yield lb	Density yield lb/ft³	Service Depth ft	Section Thickness in. (max)
VF 32	15.0	(480#)	32	3,000	6
EF 38 A	0.5	(11.5#)	41	6,000	6
EF 38 B	0.5	(10.5#)	43	12,000	6

* Emerson & Cumming, 1990

Table 3. Summary of available syntactic foam precast blocks.*

E & C Type No.	Nominal Density lb/ft³	Size Block ft³	Dimensions w - l - t in -in- in	Service Depth ft
EL 30 A	30 ±2	1	12-24-6	6,000
TG 24 A	24 ±2	1/2‡	12-12-6	6,757
EL 34 A	34 ±2	1	12-24-6	18,000†
EL 36 A	36 ±2	1⁑	12-24-6	24,000

* Emerson & Cumming, 1990

‡ Size is limited to control heat of cure (exotherm).

⁑ Man-Rated to 24,000 feet for Alvin Submersible Vehicle Certification.

† Short-term depth excursion to 20,000 feet can be accommodated.

Note: Many previously standard formulations are no longer offered for ecological reasons.

USE OF GLASS BALL FLOATS

Glass balls are commercially available in two sizes to provide flotation at ocean depths to 22,000 feet (6,700 meters). The sizes offered are 10-inch and 17-inch diameters with weights in air of 9 and 39 pounds, accordingly. The net buoyancy provided by these forms is 10 and 56 pounds, respectively. Although the depth capability and net buoyancy-per-unit characteristics are very good, the packing factor for large numbers of glass balls with their individual hard hat shells is very poor. A large assembly surface area, coupled with the complex form, will produce significant drag forces in reaction to a given environmental situation as compared with other buoy constructions yielding similar buoyancy values. Glass floats may be used for subsurface buoyancy in a number of readily accomplished ways. Possibilities include the following:

1. Individual floats distributed about a submarine structure as needed to accomplish adjustment of apparent weight in water or to achieve balance through control of the center of buoyancy location.

2. Small groups of floats may be assembled to a separable component to lift that component to an elevated position within the water column, or even to the surface.

3. Major assemblies of glass floats may be constructed about a suitable framework to achieve support for an entire system at any depth within the water column.

4. An appropriate quantity of glass ball floats with protective hard hats may simply be captured loosely inside a user-constructed cage, providing an assembly which may be transported and deployed/recovered at sea as a single piece buoy assembly.

Glass ball units can be incorporated into a user-built structure or attached to an exterior location using either net enclosures providing a single-point attachment, or in combination with molded polyethylene plastic hard hat half-shells that surround the ball with a brightly colored, rigid support and offer flanges with holes suitable for bolting to a structure or to one another. The shells are neutral density in water, giving no alteration to the properties of the glass ball except an increase in profile and drag characteristics. The packing factor of the balls and hard hats makes the task of creating a satisfactory buoy system indecisive at best. The designer may find it necessary to produce several modules to be interconnected at the time of deployment to maintain the components at a manageable overall size.

Study was given the topic of using the 10-inch variant of the glass ball float product line. The only seemingly practical application related to array construction and deployment appears to be confined to fine-tuning of weight or balance of structures principally supported by other media. The small value of net buoyancy available, combined with a large occupied volume of the hard hat, does not support the need for assemblies with a small frontal area and drag coefficient.

Construction of a buoy assembly requires only a relatively simple structure, as suggested in figure 11. The cross sectional area of a 4-inch-diameter steel pipe is more than adequate to support the buoyant forces of the combined number of glass floats; the area value for standard weight steel pipe is 3.17 square inches.

At a material allowable yield stress of 24 ksi, the load capacity, P is

$$P = S \times A = 76{,}000$$

pounds tensile load. The most severe load seen by the tube could be the bending experienced during assembly, transportation, and deployment. For the 4- inch-diameter standard pipe, the value of moment of inertia, $I = 7.23$. The moment experienced from a side load is found by the expression

$$M = \mathrm{w} \times l^2 \div 8.$$

In terms of unit stress

$$M = I \times S_a \div r$$

where r = material's distance from the neutral axis to the extreme fiber. So, a buoy assembly yielding 1,000 pounds of net buoyancy will experience a moment value of 13,583 inch-pounds, which translate into a fiber stress of 2,837 psi. Compared with an allowable stress of 24 ksi, the assembly can tolerate a lateral acceleration of about 10 g when supported horizontally by the two ends. The longest backbone of 4-inch-diameter pipe, which does not exceed the allowable stress in the horizontal posture (due to its own weight), would be 15 rows of 4 glass balls each, providing 3000 pounds of net buoyancy.

GLASS BALL FLOATS
BUOY ASSEMBLY
CANDIDATE ARRANGEMENT

SIMPLEST CONSTRUCTION IS
A CENTRAL MAST
SUPPORTING HARD HAT
ASSEMBLIES IN LAYERS OF
FOUR BALLS PER LAYERS.

ALTERNATE LAYERS NOT
SHOWN FOR CLARITY OF
ILLUSTRATION.

APPROXIMATELY FIVE LAYERS
ARE REQUIRED PER 1000
POUNDS OF NET BUOYANCY

ASSEMBLY LENGTH EQUALS
NUMBER OF ROWS X 18
INCHES PLUS LENGTH OF
END CONNECTIONS

SO, A 1000-POUND NET
BUOYANCY FLOAT WOULD BE
(5 X 18) + 12
EQUALS 102 INCHES
OVERALL LENGTH.

MINIMUM PRACTICAL
EFFECTIVE DIAMETER IS
54.5 INCHES.

LAYERS ARE
STAGGERED BY A 45-
DEGREE OFFSET TO
ACHIEVE THE MOST
COMPACT ASSEMBLY.

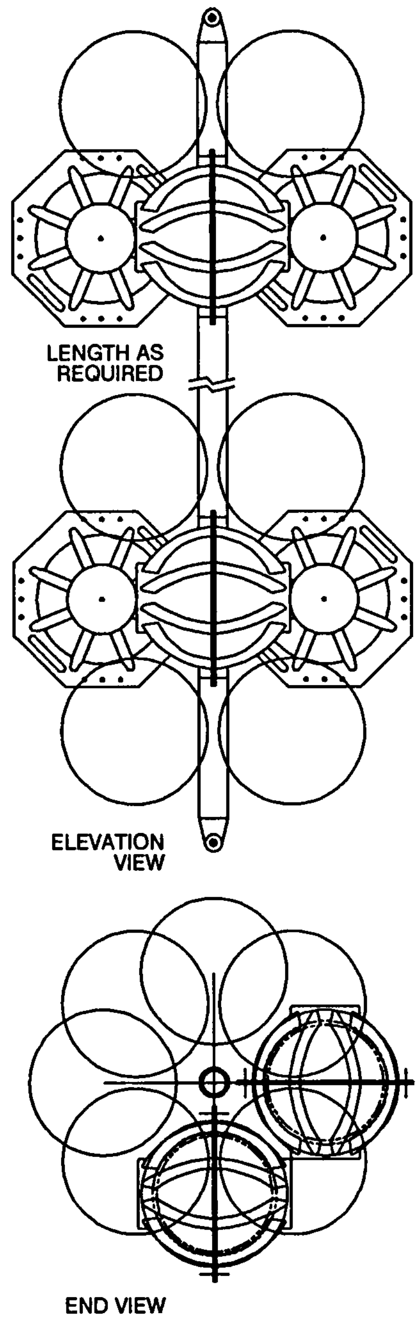


Figure 11. Simplified approach to buoy construction using glass ball floats and hard hat with tubular backbone and bolt tabs plus end fittings.

COST

FABRICATED METAL SHELL VOIDS

Fabrication of metal shells of the size and thickness required for the subsurface buoy application must use the techniques and facilities of a heavy industry facility. Accurate fabrication of smooth and regular contours is ordinarily beyond the capability of the conventional weld shop. For the most part, dies and forming tools will be required to shape the compound-curved shapes needed for all of the void shapes. In the case of the torospherical shell or end bell, the shape of the transition zone between the crown and rim contours is critical to the validity of the material strength calculations.

No attempt has been made to seriously estimate the cost of fabrication for all of the possible buoy shapes, although several commercial organizations have been contacted to establish the limitations of considering any of the possibly useful shapes.

BUOYANT MATERIALS

Combination Fabricated Shell Plus Buoyant Filler Material

Syntactic foam material kits to be cast by the user in a form (mold) created by the user at the job site of choice will incur an average cost of $5.00 per pound of buoyancy in the foam cast (not including the weight of any molded-in components. Field-cast foam systems will be limited to depth capabilities of 6000 feet of seawater or less. A service depth of 3000 feet can be realized with a foam density of 28–30 pounds per cubic foot. A tabulation of currently available syntactic foam kit materials marketed for user-cast products, their properties, and associated unit cost is given in table 2.

Premolded Syntactic Foam Disk Shapes

Commercial tooling exists to fabricate disk-shaped floats of syntactic foam with an integral laminated GRP shell; a cost of approximately $5.00 per pound of buoyancy can be obtained through the specification of shapes and characteristics, which take advantage of pre-existing tooling inventoried by the manufacturers. The initial cost of tooling to the customer's specifications will be roughly four times the cost of the first product. The advantage of this fabrication technique lies in the excellent finish of the completed object and in the uniform quality of the cured foam.

Syntactic Foam Precast Block Assemblies

Precast blocks of syntactic foam are available from commercial sources in generic rectangular shapes of 1 cubic foot in a size of 12 by 24 by 6 inches. The thickness usually represents a maximum for the reliable casting of the chemicals used. If the section thickness were allowed to be greater, failure of the material due to excessive heat generation would be likely. Some of the block shapes are limited to 12 by 12 by 6 inches because of the same consideration. In recent months, several of the commonly produced compounds have been dropped from the product line because of environmental or health restrictions on the chemicals used. A summary of the currently available precast block products and their cost data are given in table 3. Use of the precast blocks as major buoyancy requires that the individual blocks be converted into a unified system to function as a buoy. This may mean a supporting structure, enclosure, or bonding of the parts into a compatible whole. Each approach ends up being a compromise between weight, durability, and convenience in assembly and handling. These considerations are in addition to justification of the substantial initial cost of the material as a trade-off to the assurance that the assembly will reliably withstand the full intended operational depth, even in the event of a significant infliction of accidental damage.

The cost varies in proportion to the specified depth of operation. Formulations produced for full ocean depth to 80% ocean depth cost

proportionally more than shallower ratings. Summarized in terms of cost per 1000 pounds of buoyancy, the material loses some of the initial appeal. The following figures, table 4, represent the precast syntactic foam only; the weight of a supporting structure or enclosure would be subtracted from the net buoyancy values given.

GLASS BALL FLOATS WITH HARD HAT SHELL

Glass ball floats presently commercially available are offered in the form of two hemispheres with the facing edges ground flat, then assembled with sealant applied to the mating faces and evacuated during the assembly process. The resulting product is tightly joined by atmospheric pressure providing around 3000 pounds of external force across the joint. Benthos is the only remaining known domestic maker of this product. The current price list offers two sizes of ball, 10-inch-diameter and 17-inch-diameter. The protective hard hat of molded polyethylene is offered as an optional extra. The shells are neutrally buoyant, dense enough to provide protection against point impact and abrasion types of handling abuse, and provide flanges for attachment of the float to one another or to a structure. The shells are offered in four styles with various flange and rib configurations. In addition, a woven net enclosure with a single-point attachment is available. Procurement costs vary with quantity and breakdown as shown in table 5.

Table 4. Cost of syntactic foam applications in terms of dollars per 1000 pounds lift.

Type Number	Density Material lb/cu-ft	Buoyancy Yield lb/cu-ft	Depth Rating ft	Cost* per cu-ft $ 1990	Cost per 1000# $ 1990
Cost data for precast syntactic foam block applications (not including any assembly or structure)					
EL 30 A	30	34	6,000	880	26,400
TG 24 A	24	40	6,757	1374	34,350
El 34 A	34	30	18,000	862	28,734
EL 36 A	36	28	24,000	1047	37,393
Cost data for syntactic foam user-cast kit materials				(kit cost)	
VF 3	32	32	3,000	1960	4,145
EF 38 A	41	23	6,000	159	13,826
EF 38 B	43	21	12,000	226	21,523

* Emerson & Cumming, 1990

Table 5. Glass ball and shell costs.

Item Float	Quantity 17-inch	1–45 $290	46–135 $276	136 + $262	Cost of 1000 lb of buoyancy* (20 floats at low – hi price break)		
Shell	# 204H	77 (367)	74 (350)	71 (333)	7340	7000	6660
"	# 204HR	77	74	71			
"	# 204SRO	118 (408)	112 (388)	107 (369)	8160	7760	7380
"	# 204SRM	118	112	107			
Net	# 204N	46 (336)	46 (332)	46 (308)	6720	6440	6160

* Benthos, Inc. October 1989 Price Schedule

( ) Cost of float with hard hat at quantity price break

Distributed Individual Floats

Individual attachment of glass floats to the instrumented section of an array assembly (presumably to support individual components or to adjust local net buoyancy) is most simply accomplished by the use of a net bag to hold the float and provide a single attachment eye for joining to the array assembly. The thickness of the netting is sufficient to prevent contact of the glass with adjacent flat surfaces. The most serious drawback will be the asymmetry of the arrangement, both for drag considerations and the inconvenience presented to handling tasks into and out of the water. During deployment and retrieval evolutions, dangling glass ball attachments tend to catch on everything in sight. Since the nature of glass ball floats does not accommodate a need for symmetry without resorting to penetrations and a through tube, consideration should be given to the use of molded elliptical floats made of syntactic foam, which can straddle a cable or structural member. From table 5, the installed cost of a few glass floats confined by netting is $336 each in quantities between 1 and 45, $322 each in quantities up to 135 pieces, and $308 each for larger numbers of units. So, a three-leg array requiring 10 floats per array leg, yielding 550 pounds of buoyant support per leg, would cost $10,080 for 30 float assemblies.

Assembly of Floats in Fabricated Framework

Concentrated units of buoyancy can be obtained by attaching individual floats (with the hard hats installed) to a suitable fabricated framework. A candidate configuration, which could provide up to 5000 pounds of net buoyancy using 25 layers of 4 floats each, is suggested in figure 11. Floats are arranged in staggered layers of four floats per layer. Staggering the adjacent rows 45 degrees apart permits some compaction of height. Each two-row set (8 floats) can be spaced as little as 36 inches on centers. A construction embracing 100 floats, allowing 5 pounds per float for structure, will provide close to 5000 pounds of net buoyancy when installed in the ocean. Cost to construct such a system will tally approximately $42,000, based on the quantity price information given in table 4.

FLUID-FILLED SHAPES

Liquid-Filled Containers

Seal Bin

Seal bins are durable fabric-reinforced rubber cylindrical structures closed by steel end plates. The rubber construction is backed up by an internal chain or wire rope connecting the two end plates. A 2-inch-diameter NPT standard bung is incorporated into one of the end plates. Each end plate incorporates a swiveling bail capable of lifting the entire drum and contents. The intended use of the drum is for field combat and amphibious landing support, and therefore is a very durable construction. The drums are extremely sturdy and durable and will survive for a very long time in an immersed installation. Inquiries are still in process at this writing to determine whether the item still exists in the Navy Supply System, and at what cost and availability.

Dunnage Bladder

Dunnage bladders are constructed to provide isolation between delicate cargo and the shock and vibration found in truck, rail, air, and shipboard transportation vehicles and are mentioned here because of their very tough construction. The envelopes could be considered as a flexible attached buoyancy envelope or as a liner for a shell. The bladders are intended to be inserted beneath a pallet or crate and the supporting deck, then are partially filled with a convenient fluid such as water. The result is a "waterbed" for cargo. The most vulnerable part of the system is the possibility of point chafing on corners or sharp edges when in transit. Rings and eyelets are provided for handling and tie down attachments. If considered for the containment of buoyancy fluid, the bladders would probably best serve if combined with a net or lightweight shell to distribute buoyancy over the maximum support area and provide appropriate attachment points for transfer of the developed buoyant force.

Thinwall Tank

Both of the above devices are flexible in nature and can accept compression with depth as well as hard attachment points. A thinwall tank, on the other hand, is inflexible and will not conveniently accommodate the change of volume associated with deep ocean excursions. Therefore, a tank of light construction, which is to be filled with buoyant fluid, must also incorporate a volume compensation system in the nature of a bellows, piston, bladder, or diaphragm to enable compliance with the inevitable volumetric variation with depth. Otherwise, a tank of minimal construction would be completely practical for consideration in the provision of deep water buoyancy. Provision of hard points on the tank structure is required to accommodate the loads of handling and installation required in addition to the normal connection points for the load to be supported in the installed configuration.

In addition to the above observations, a combination system is also possible. Using one of the soft bladder types described above as a liner for a thin shell tank in combination with a fluid buoyancy medium would produce a system less vulnerable to minor abuse in deployment, impervious to fish-bight, stall light in total immersed weight, capable of field assembly, and manageable with less complex handling equipment. The metal shell could conceivably comprise segments to be assembled at the time of deployment and, as such, would require less shipboard deck space to stage in transit than a complete pre-assembled buoy system.

Gas-Filled Containers

Salvage Pontoon

Salvage pontoons are commercially produced for use with air to provide temporary buoyancy for salvage of handling tasks. Lift capacities, filled with air, are available ranging from a few tens of pounds to 77,000 pounds of net buoyancy if fully inflated. The traditional envelope shapes are either teardrop or cylindrical. Lift bags are equipped with connections and bleed valves intended for use with compressed air or other gas media. The bleed valve is incorporated to allow over-pressure gas to escape, as when a laden pontoon is released from depth to rise to the surface. As ambient pressure diminishes with depth, the enclosed gas will expand to overfill the pontoon and thus must be bled away.

Work has been done in the production of gas in situ for the inflation of submerged objects. The technical dictionary describes the reaction as follows:

$$\begin{array}{c}\text{MONOHYDRATE} \nearrow \\ NH_2\,NH_2 \rightarrow NH_2\,NH_2 \cdot H_2O + \text{SALTS}\end{array}$$

No investigation of the status of development of the hydrazine gas generation equipment or techniques has been attempted in conjunction with this report.

Custom Fabricated Envelope

Vendors such as those supporting the salvage pontoon market are usually willing to consider the manufacture of special bags with custom shapes, sizes, fittings, or materials in consideration of an appropriate fee.

DERIVATION OF SHAPES

METAL SHELL PRESSURE VESSELS

Metal spinning services are available* to form mild steel blanks up to 180 inches in diameter and 6 inches thick. The capability can form halves of buoy forms including sphere, ellipse torosphere, and possibly the torus as well. Preparation to use this service involves determination of the volume, proportions, and thickness of the shell needed to withstand the intended service conditions. Similarly, the design of cylindrical buoy forms follows the same sequence of steps. In this section, it is intended to iterate the equations pertinent to the properties of each shape and plug the numbers for a presumed buoy shape displacing 10,000 pounds of seawater, which is a volume of 155.52 cubic feet. Derivation of thickness of the shell will be based upon a presumed service/excursion depth of 2000 feet, equal to an ambient pressure of 892 psi. It will be presumed that the material of choice shall be mild steel with an allowable yield stress of 24 ksi. The data given here represent the outer shell only and do not incorporate any design for attachment points, gussets, feed-through tubes, or stiffeners.

CYLINDRICAL SHAPES

Plain Cylinders

Plain cylinders with flat end plate closures are, as it turns out, inappropriate for service as buoys at any depth greater than their own diameter (see figure 12). The dimensions for a cylinder of equal length and diameter displacing the model volume of 155.52 cubic feet of water, i.e., 70-inch diameter, required an end bung more than 4 inches thick to withstand a working depth of 2000 feet. See the spreadsheet computation results in appendix A for comparative values. The disparity between the cylinder wall thickness and the end bung thickness for equal strength characteristics

SUBSURFACE BUOY CONFIGURATION
SIMPLE CYLINDER

DISPLACEMENT: 10,000 POUNDS OF SEAWATER
NET BUOYANCY: 5,000 POUNDS
DENSITY OF STRUCTURE: 0.5

$$V_B = \frac{B}{W_{H_2O}} = \frac{10,000\ lb}{64.3\ lb/ft^3} = 155.52\ ft^3$$

$$V_{cyl} = A \bullet L \quad A = pi\frac{D^2}{4} \quad L = D$$

$$V_{cyl} = pi\frac{D^2}{4}L \quad V_{cyl} = pi\frac{D^3}{4}$$

SOLVING: $D_{cyl} = \sqrt[3]{\frac{4V}{pi}} = 5.828\ ft$

$L = 5.828\ ft$

CYLINDER WALL THICKNESS

$$t_w = \frac{Pr}{Sa} = 1.2998\ in.$$

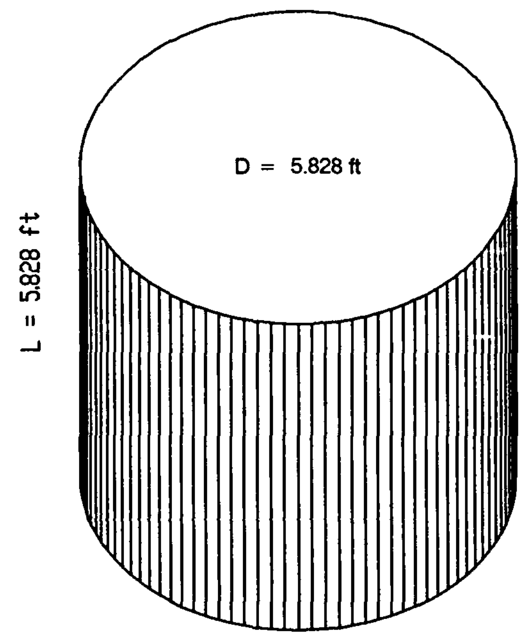
$$t_e = \sqrt{\frac{3\ PA_e(m+1)}{8\pi m Sa}} \qquad P = 892,\quad m = 1/\nu,\quad \nu = 0.27\ \text{(mildsteel)}$$

$t_e = 4.6528\ in.$

WEIGHT: $W_b = W_w + W_e = 40.8 \times A_S x t_1$

$W_b = 14,785.9\ lb$

BUOYANCY: $B_b = D - W_b = -4785\ lb$



FRONTAL AREA = $A_f = LD = 33.966\ ft^2$
SURFACE AREA = $2\pi r^2 + L\pi D = 160.06\ ft^2$
DRAG COEFFICIENT: $C_d = 0.63$

Figure 12. Definitions of parameters for a simple cylinder with flat plate ends.

* Personal communication with Gary Ehn, 20 July 1990.

also produces very difficult joint conditions. In fact, these calculations do not include the added stress produced at the wall/end junction due to bending moments associated with the fixed edge joint condition.

Complex Cylinders

The tricylinder concept is similarly affected by plain end closure considerations; however, the severity is diminished by the smaller diameter of the individual floats used in the tricylinder construction (see figure 13). Therefore, to use the simple contour of the easily rolled cylinder wall, one must resort to a complex end-bell shape to avoid a fabrication of excessive weight or impossible joinery. The candidates are (1) hemispherical, (2) semielliptical, and (3) toro-spherical (including dished and flanged) as illustrated in figure 4. Each shape will yield a section thickness near the wall thickness of the host cylinder, but the equations in the literature do not support the application to great pressure. This situation will force the development and proof- testing of shapes for the deep water application.

SUBSURFACE BUOY CONFIGURATION
COMPLEX CYLINDER

DISPLACEMENT: 10,000 POUNDS OF SEAWATER
NET BUOYANCY: 5,000 POUNDS

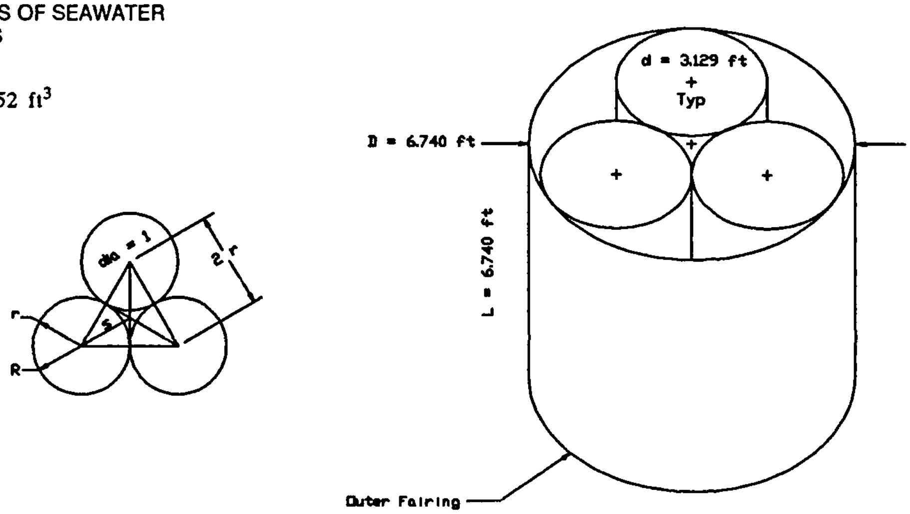
$$V = \frac{B}{W_{H_2O}} = \frac{10,000 \text{ lb}}{64.3 \text{ lb/ft}^3} = 155.52 \text{ ft}^3$$

$$R = r + s \quad s = \frac{2r}{3} \cot 30°$$

$$R = r\left[1 + \frac{2}{3} \cot 30°\right]$$

$$D = 2R$$

$$L = D$$



for each interior cylinder:

$$v = \frac{\text{pi}d^2 L}{4} = \frac{\text{pi } 2.154 \, d^3}{4}$$

$$d = \sqrt[3]{\frac{4v}{2.154 \text{ pi}}} = 3.129 \text{ ft}$$

for Outer Fairing diameter

$$D = L = 2.154 \quad d = 6.740 \text{ ft}$$

FRONTAL AREA: $A = L \cdot D = D^2 = 45.428 \text{ ft}^2$

SURFACE AREA: $A = \text{pi } D \cdot L = 142.715 \text{ ft}^2$

DRAG COEFFICIENT: $C_d = 0.63$

Figure 13. Derivation of equations for the proportions of a triple cylinder buoy with fairing.

SPHERE

The spherical form is the most straightforward and obvious shape for subsurface buoy implementation, although it is not necessarily the easiest to fabricate. Spheres represent the most compact enclosure for a given volume, and stress in the material is uniform throughout the shell. This presumes, of course, that the shape is true and not subjected to dents or changes of section thickness. The standard properties are shown in figure 13, and the calculations for a range of sizes are given in appendix B. The equations used are from Roark (1965). Review of the expressions found in the *Pressure Vessel Handbook* (Megyesy, 1973) and in *Pressure Vessel Design Handbook* (Bednar, 1981) shows that the wall thicknesses of vessels fabricated to domestic code are considerably thicker than that computed from Roark. The discrepancy is produced by the code allowances for weld efficiency, corrosion, and wear and tear throughout a projected service life. The corresponding considerations for subsurface buoy application will be quite different and probably implemented through restriction of allowable stress in the governing calculations. The allowance will be tailored to the specific needs of a subsurface buoy for short duration service to be assembled, deployed, and tended by specialist personnel.

SUBSURFACE BUOY CONFIGURATION – SPHERE

DISPLACEMENT: 10,000 POUNDS OF SEAWATER
NET BUOYANCY: 5,000 POUNDS
DENSITY OF STRUCTURE: ASSUMED AT 0.5

$$V_B = \frac{B}{w_{H_2O}} = \frac{10,000\ lb}{64.3\ lb/ft^3} = 155.52\ ft^3$$

$$V_{sphere} = \frac{4}{3} pi r^3 \quad r = \sqrt[3]{\frac{3V}{4pi}} = 3.34\ ft$$

$D = 2r = 6.67\ ft\ (2.034m)$

FRONTAL AREA: $A_f = pi\ r^2 = 35.046\ ft^2$

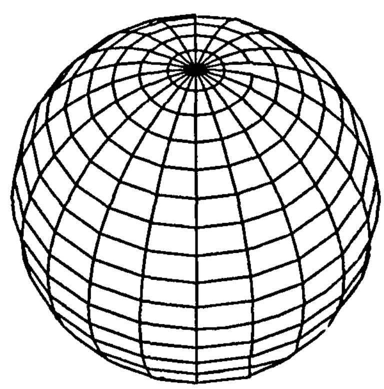
SURFACE AREA: $A_s = 4pi\ r^2 = 140.19\ ft^2$

REQUIRED WALL THICKNESS: $t = \frac{12\ pr}{24\ S_a}$ $S_a = 24\ ksi$

$t = 0.744$ in

WEIGHT: $W = A_s 40.8 \quad t = 4.255.5\ lb$

THIN SHELL WEIGHT (1/8 PLATE): $W = 5.1 \quad A = 715.0$



DRAG COEFFICIENT: $C_d = 0.50$
SERVICE DEPTH: 2000 ft
SERVICE PRESSURE: 892 psi

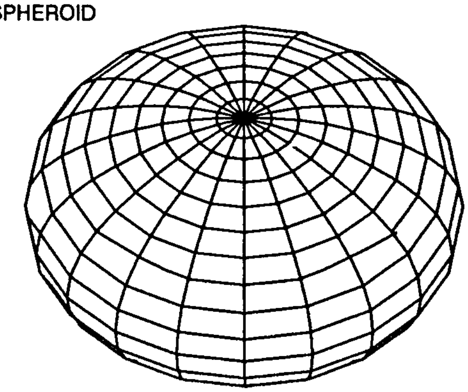
Figure 14. Derivation parameters for a spherical buoy.

ELLIPSOID

In the context of this dissertation, an ellipsoid is actually an oblate spheroid, that is, a sphere compressed to a specified percentage of the full height along the vertical axis of rotation. In mathematics, a true ellipsoid is considered to be elliptical in cross section about all three mutually perpendicular planes. The buoy interpretation is circular in the $x - y$ plane and equally elliptical in both the $x - z$ and $y - z$ planes. Straightforward equations are available in the literature to compute volume and cross-sectional area parameters, but expressions to determine surface area are complex. However, once we were able to interpret the expression for eccentricity, the available expression was made to work with correct results.

SUBSURFACE BUOY CONFIGURATION – ELLIPSOID

ELLIPSE OF REVOLUTION ABOUT THE MINOR AXIS GENERATES AN OBLATE SPHEROID



DISPLACEMENT: 10,000 POUNDS OF SEAWATER
NET BUOYANCY: 5,000 POUNDS
DENSITY OF STRUCTURE PRESUMED AT 0.50

TAKE RATIO OF WIDTH TO HEIGHT AS 1.8:1

$$V_{Buoy} = \frac{Disp.}{W_{H_2O}} = \frac{10,000\ lb}{64.3\ lb/ft^3} = 155.52\ ft^3$$

$$V_{s-p} = \frac{4}{3} pi w^2 b = \frac{4}{3} pi \frac{w^B}{1.8}$$

w = MAJOR SEMIAXIS OF ELLIPSOID
b = MINOR SEMIAXIS OF ELLIPSOID
a = ASPECT RATIO $= \frac{w}{b} = 1.8$
SO, $b = \frac{w}{1.8}$

SOLVING:

$$w = \sqrt{\frac{5.4V}{4pi}} = 4.058\ ft$$

$$b = \frac{w}{1.8} = 2.255$$

DIAMETER: $D = 2w = 8.116\ ft$

HEIGHT: $H = 2b = 4.510\ ft$

FRONTAL AREA: $A_f = pi\ w\ b = 28.748\ ft^2$

SURFACE AREA: $A_s = 2\pi w^2 + \frac{b^a}{e}\ ln\ \frac{1+e}{1-e}$ $\quad e = \frac{\sqrt{a^2 - b^2}}{a}$

$A_s = 149.30\ ft^2$

WALL THICKNESS: $t = \frac{PD_0}{2SE + 1.8P} = 1.751$ inches at 24 ksi

WEIGHT: $W = A_s \times t \times 40.8 = 10,666.1\ lb$

THIN SHELL WEIGHT (1/8 PLATE): $W = 5.1 \quad A = 761.4\ lbs$

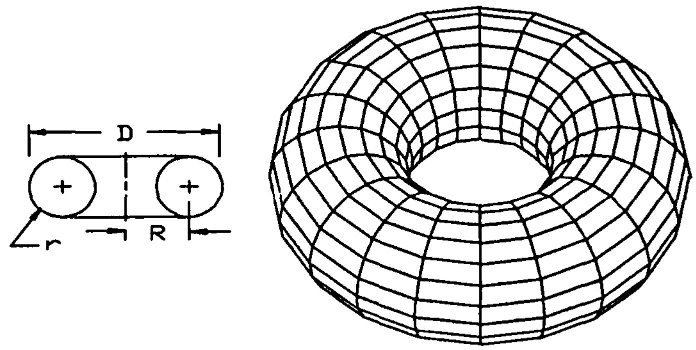
Figure 15. Mathematical data for ellipsoidal buoy shell with specimen value calculations.

TORUS

SUBSURFACE BUOY CONFIGURATION – TORROID

DISPLACEMENT: 10,000 POUNDS OF SEAWATER
NET BUOYANCY: 5,000 POUNDS
DENSITY OF STRUCTURE PRESUMED AT 0.50

$$V_B = \frac{\text{Disp.}}{W_{H_2O}} = \frac{10,000 \text{ lb}}{64.3 \text{ lb/ft}^3} = 155.52 \text{ ft}^3$$



SECTION RADIUS: r
RADIUS OF REVOLUTION: R
SET R = 2 r *
$V_{Torus} = 4\ pi^2\ r^3$
SOLVING:

* ARBITRARILY ASSIGNED PROPORTION

$$r = \sqrt[3]{\frac{155.52}{4\ pi^2}} = 1.579 \text{ ft}$$

$R = 2r = 3.159$ ft
DIAMETER: $D = 6r = 9.474$ ft
SURFACE AREA: $A_s + 4\pi^2 R\ r = 196.92 \text{ ft}^2$
FRONTAL AREA: $A_f = pi\ r^2 + 8r = 42.178 \text{ ft}^2$
DRAG COEFFICIENT: $C_d = 0.20$
SERVICE DEPTH: 2000 ft
WORKING PRESSURE: 892 psi
MATERIAL THICKNESS: $t = \frac{Pr}{2S} = \frac{892 \times 18.594}{2 \times 24,000} = 0.352$
WEIGHT: $W = A_s \times 40.8 \times t = 3012.9$ pounds
WEIGHT OF THIN SHELL: (1/8 PLATE)$w = A \times 40.8 \times 0.125 = 1004.29$ pounds

Figure 16. Development of torus as a buoy shell with specimen calculations.

A torus (figure 16) implemented as a buoy takes the form of an annular ring with a hollow circular cross section. As previously stated, the torus form offers freedom from drag-couple pitch motions and allows the suspension of ancillary objects through the central opening. On the surface, however, the shape follows the prevailing waveform faithfully. This property produces very exaggerated pitch motions with respect to components connected to the underside of the float, with the resultant danger of bending the attachment hardware. These conditions reverse once the shape is pulled beneath the surface.

Considerable research has been performed in the general area of hydromechanically loaded shells in the pursuit of improved designs for pressure resisting shell constructions, with regard to buoy construction as well as for enclosures for underwater equipment. The *Proceedings of the 1973 Symposium of the International Association for Shell Structures-Pacific Symposium* (Sziland, 1973) has been published as a volume of collected papers and discussions. Of particular interest is a paper on the analysis of the behavior of unstiffened torroidal shells. An in-depth mathematical analysis well beyond the scope of this paper is presented therein. Another article of interest for study is "Pertinent Shell Theories and Methods for Analysis." Discussions of ring-stiffened shell construction is also covered.

TORUS WITH SPHERICAL FAIRING

TORROID CROSS SECTION WITH SPHERICAL FAIRINGS ON TOP AND BOTTOM FACES

CALCULATIONS FOR 10,000-POUND DISPLACEMENT TORROIDAL BUOY

(ADDED FAIRINGS SHOWN AS DASHED LINES)

$$R = r + \frac{\omega}{\sin 2\left(\tan^{-1}\frac{h}{\omega}\right)}$$

$A = \frac{W}{H}$ = ASPECT RATIO = INPUT VALUES

$H = r + h$

$W = \omega + r$

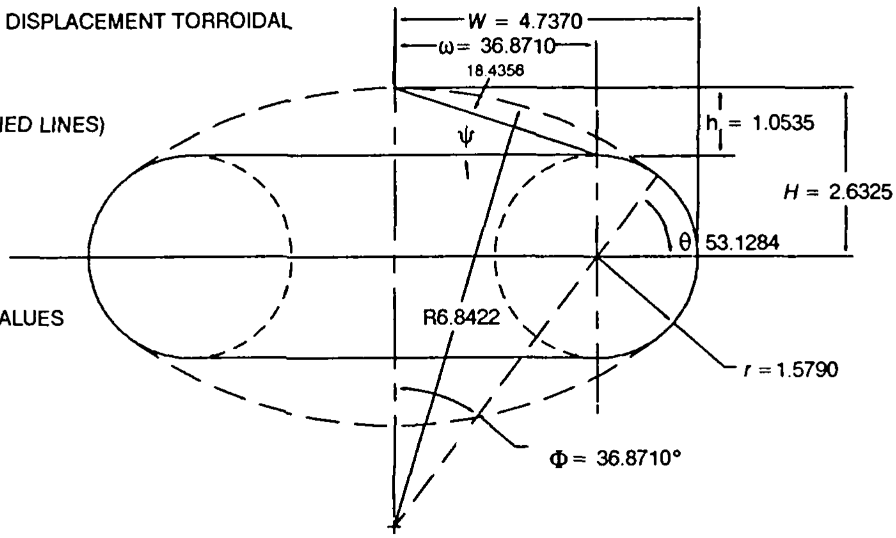


Figure 17. Spherical fairing added to torus buoy.

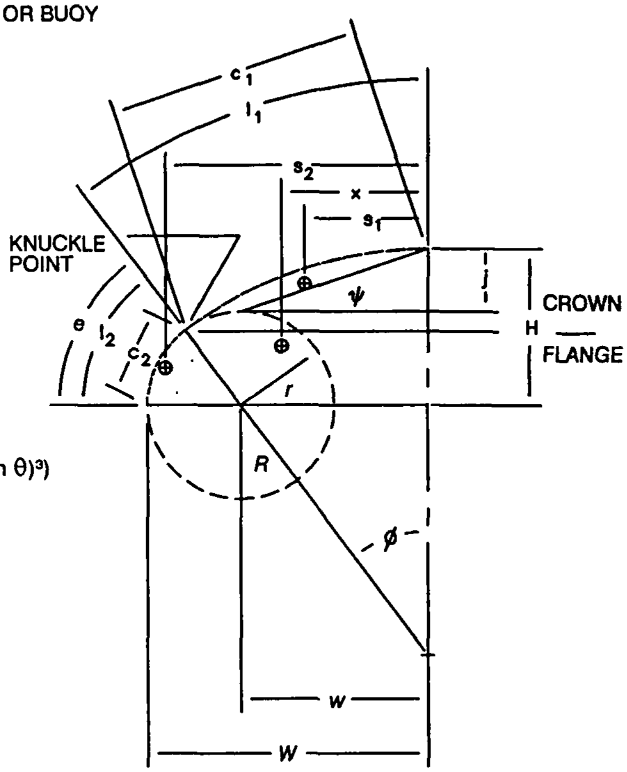
These calculated parameters describe the values needed to lay out and fabricate a spherical fairing to be added to the structure of a torroidal buoy construction (Tauma, 1970). The example torus buoy proportions using a cross-section radius of one-sixth of the outside diameter happens to coincide almost exactly with the profile of an ellipse when fitted with a spherical crown calculated with the expressions given in figure 16. We did not set out to find such a match; it was found by coincidence. Construction of fairings of glass-reinforced plastic polymer (fiberglass imbedded in epoxy or polyester resin) will be close to neutral density in the water. Addition of syntactic foam or captive glass floats to the construction can be used as a means of increasing net buoyancy or adjustment of the center of buoyancy for the composite structure.

TOROSPHERICAL

The torosphere has been described as a dome shape defined by a spherical crown bounded around the edge by a flange of a smaller radius, usually selected to be a particular proportion to the diameter of the disk. In external appearance, the torosphere resembles the elliptical shape, but not exhibiting as smooth a contour transition near the flange. The parameters of the shape are readily calculated, if somewhat clumsily by comparison to sphere or cylinder (see figure 17).

CALCULATIONS FOR VOLUME OF A TOROSPHERICAL END BELL OR BUOY

W	assigned major semiaxis	
a	assigned aspect ratio height to diameter	
f	assigned flange to major radius ratio	
H	height	W/a
r	radius of flange shape	f/W
j	calc parameter	$H - r$
w	calc parameter	$W - r$
ψ	calc parameter	$\mathrm{atan}(j/w)$
ϕ	crown arc half angle	2ψ
θ	flange arc swept angle	$90 - \phi$
c	crown height	$H - r \cos \phi$
R	crown radius	$r + w/\sin \phi$
V_c	volume of crown	$\pi/3\, c^3(3R - c)$
V_f	volume of flange	$\pi(W^2 r \sin \theta - 1/3(r \sin \theta)^3)$
V_e	total volume of end bell	$V_c + V_f$
V_b	total volume of buoy	$2\, Ve$

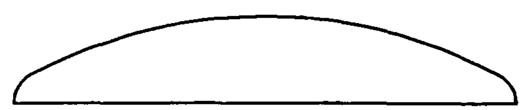


DISHED AND FLANGED END BELL, R IS ASSIGNED
FAMILY OF EQUATIONS IF R IS SET EQUAL TO DIAMETER

D	overall diameter of bell	selected
f	flange ratio to diameter	selected
R	radius of crown	$R = D$
r	flange radius	$f D$
L	hypotenuse of construction angle	$R - r$
w	*center-to-center flange/crown*	$D/2 - r$
ψ	half arc of crown radius	$\sin w/L$
H	crown height	$R - h$

CALCULATIONS FOR THE SURFACE AREA OF A TOROSPHERICAL END BELL OR BUOY

l_1	crown arc length	$2\pi R\phi/360$
$c1$	crown arc width	$2R \sin(\phi/2)$
d_1	radius of CG from center of arc	$(R\, c_1)/l_1$
s_1	horiz position of CG from C_L	$d_1 \sin(\phi/2)$
l_2	flange arc length	$2\pi re/360$
c_2	flange arc width	$2r \sin(e/2)$
d_2	flange CG radius	$(r\, c_2)/l_2$
s_2	flange CG radius from C_L	$d_2 \cos(e/2) + w$
x	radius of composite CG from C_L	$(l_1 s_1 + l_2 s_2) / (l_1 + l_2)$
A_s	surface area of end bell	$2\pi\ x\, (l_1 + l_2)$
A_b	surface area of complete buoy	$2\ A_s$
M	knuckle stress factor*	$(3 + \sqrt{R/r})/4$
t	shell material thickness	$PRM/2S_a + P(M - 0.2)$
W_s	weight of an end bell	$40.8\, A_s\, t$
W_b	weight of buoy shell	$2W_s$
W_t	weight of a thin (1/8 R) shell)	$40.8\ x\ 0.125\ x\ A_s$
A	bell frontal area	$\pi R^2 \frac{\phi}{360} - wh + \pi r^2 \frac{e}{360}$



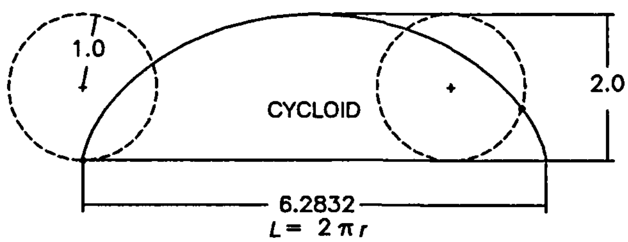
DISHED AND FLANGED PROFILE
$R = D$
$f = 16$

* REFERENCE PRESSURE VESSEL DESIGN HANDBOOK, E. F. MEGYESY, PRESSURE VESSEL HANDBOOK PUBLISHING INC., TULSA, OK. 6TH ED., JULY 1983.

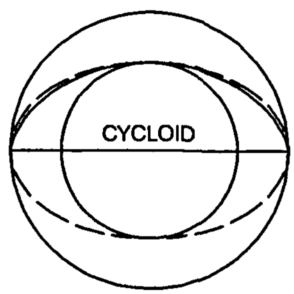
Figure 18. Calculations pertinent to development of a torospherical shape.

CYCLOID

A cycloid is the locus of points described by a fixed point on the circumference of a circle as that circle is rolled one full revolution along a flat surface (figure 19). The resulting curved line is remarkably similar to the semielliptical and semi-torospherical outlines described above. No attempt will be made here to develop the shape as a pressure vessel. To do so will require derivation of expressions from the integration of general equations to make possible the calculation of volume, surface area, frontal area, skin thickness, weight, and buoyancy. A buoy or end bell shape would be the result of creating a body of revolution based upon one-half of the profile illustrated. Calculations of volume and surface area alternatively can be found using the radius of the center of gravity of the cross-sectional area and of the outline shape, respectively. General equations for the derivation of needed data can be found in (Hudson, 1944, and Swokowki, 1979).



A: GENERATION OF CYCLOID SHAPE



B: RELATIONSHIP OF CYCLOID TO ELLIPSE, INSCRIBED AND CIRCUMSCRIBED CIRCLES

Figure 19. Derivation of a cycloid outline with relationship to familiar shape outlines.

An AutoLisp routine has been created to operate within AutoCad Drawing Program to create the illustration given as figure 19. The mathematical expressions used to compute the shape are taken from Tauma (1970). The source listing follows.

```
;lisp routine to construct a polyline cycloid shape based on
;a generating circle of "r" radius

(defun c:cycloid ()
  (setq r (getreal "\nEnter a value for the Radius: "))
  (setq p1 (getpoint "\nPick the beginning point of the Baseline: "))
  (setq L (* (* pi r) 2))
  (setq p2 (list (+ (car p1) L) (cadr p1)))
  (setq a 0)
  (setq p3 p1)
  (command "line" p1 p2 \r)
  (while (<= a (* (/ pi 2) 4))
     (setq x (* r (- a (sin a))))
     (setq y (* r (- 1 (cos a))))
     (setq p4 (list (+ (car p1) x) (+ (cadr p1) y)))
     (command "line" p3 p4 \r)
     (setq p3 p4)
     (setq a (+ a (/ pi 20))); The shape is constructed of 20 segments, for more or less segments,
                             ; change the value in the parenthesis.
  ) ;end while
  (setq p5 (list (+ (car p1) (/ l 2)) (- (cadr p1) (/ r 2))))
  (setq msg "cycloid!")
  (command "text" "c" p5 (/ r 2) 0 msg \r
   "redraw" \r)
)end defun
```

CONCLUSIONS

Of the variety of buoy forms presented in this report, many are inappropriate for service at the model depth of 2000 feet. Some of the rejected shapes will be subject to thin shell buckling, even though the calculated section thickness should be ample. The reason stated for this behavior is that the service depth is beyond the range of validity of linear equation solutions. Other candidates must be rejected on the grounds that the structure, while adequate, is no longer buoyant at the required strength. Such designs are, therefore, only suitable as pressure resisting voids to contain pressure intolerant systems, i.e., enclosures for instrumentation. Physical support (buoyancy) must be provided by other means.

Taken in the order of introduction, the suitability of the various developed shapes as a subsurface buoy is presented below with an accompanying rationale statement and excerpts from the spreadsheet calculations, which were constructed to explore a representative range of design proportions.

The spreadsheet output listings and their associated formula structures are included in the appendices attached to this report.

These concluding statements give a numeric acceptability factor based on an arbitrary scale of 1 to 10.

METAL-SHELL VOID BUOYS

All of the metallic buoy shapes discussed here are simple shell configurations. No rib-stiffened or otherwise reinforced forms have been included in the investigations.

Cylinder

Cylinder shapes investigated and presented herewith are limited to an L:D aspect ratio of 1 in deference to the preferred coefficient of drag target obtained from Meyers (1969). Larger values of aspect ratio will provide additional volume to offset the proportionally great weight of flat end bungs, as witness the comparison to be seen between single 1:1 cylindrical buoys and the tricylinder individual float variant. Cylindrical buoys do not offer a convenient geometry for attachment of the load to be supported, accommodation for the passage of equipment conductors, or mounting of support equipment enclosures.

Cylinder, Flat Ends

A design for 2000 feet in the range of sizes between 1000 and 25,000 pounds of gross displacement yield an efficiency factor of -57.07%, that is, much heavier than water.

Acceptability as an appropriate design configuration — 0

Cylinder, Hemispherical Ends

A cylindrical buoy modified to incorporate hemispherical end bells to produce an efficiency value of 62.75%, which is superior to the value obtained from a pure sphere construction; again the improvement being due to the volume contribution of the cylinder wall. The overall length of the design is considerably greater than the 1:1 target value for the category. A coefficient of drag for the form would probably have to be derived by experiment.

Acceptability factor — 8

Cylinder, Semielliptical Ends

The cylinder with semielliptical end bells was investigated for eight configurations of increasingly flatter end bells. The efficiency computation for these combinations ranged from a best of 26.42% to a poorest value of 24.08%. These quantities show the burden of the diminishing volume of the flatter end bell, although the material thickness required remains constant for a given diameter.

Acceptability factor — 6

Cylinder, Torospherical Ends

Incorporation of the torospherical end bell with a cylindrical body is similar in most respects to the semielliptical configuration above. Considerably more variants are possible to construct, and the texts (Bednar, 1981; Megyesy, 1973), assert that fabrication of the torosphere to specification is less costly than that for an elliptical form. The torospherical buoy constructions show a wider range of efficiency values, between 49.19 and 16.97%. The poorer performances are in direct proportion to the radius of the crown contour: the flatter the crown, the greater the material thickness required and, hence, the greater weight of construction. Additionally, the texts do not advocate the use of torospherical shapes in pressure regimes greater than 150 psi, thus establishing a need to perform development and testing.

Acceptability factor — 6

Cylinder, Dished and Flanged End Bells

The dished and flanged (D/F) end bell construction is the same derivation of form as the torospherical application discussed above, but the variations of form are limited to the flange radius as a proportion of the diameter. The crown radius is always held to equal the diameter. Even so, a range of possibilities is available offering slightly better overall efficiencies in combination with a cylindrical body than the torospherical family of shapes. However, the 150-psi limitation applies equally, and use of the shape for whatever feature is attractive will require an investment in development and testing.

Acceptability factor — 6

TRICYLINDER BUOY CONFIGURATIONS

As a family, the tricylinder arrangement offers greater efficiency of performance than similar constructions of single buoys of 1:1 proportions, owing to the proportionally greater length of cylindrical section for other dimensions being equal. Constructions that remain usefully buoyant in a design for 2000 feet of ocean depth are possible, although the efficiencies obtained may suggest leaning in another direction. The principal point of determination will ultimately be based upon whether or not the separable buoy cluster is desired. Other methods of producing separable buoy clusters could be contrived to offer a superior packing factor in the assembled system. In general, individual float efficiencies are quite good, but three floats in combination with an outer fairing of 1/8-inch steel plate fair poorly in the smaller sizes.

Acceptability factor — (one point superior to the respective cylinders above)

Spherical

Plain spherical shell buoys offer an efficiency factor of 57%, not including fittings, attachments, or provision for accessories such as a system junction box. Spherical shells are demonstrated to be stable and reliable at large pressure ratings, so long as the form remains true. Distorted shape, i.e., dents, will nullify the validity of calculated strength and result in failure at some pressure less than the design value. Modification of the spherical shell to incorporate a wet well for accommodation of cables, junctions box, and other accessories was considered and is reflected in the spreadsheet calculations for the purpose of adjusting the buoy size to compensate for the lost volume. What is not included in the calculations is the structural stiffening needed to accommodate the lost shell segment and the accompanying added weight.

Acceptability factor — 7 (plain shell)
— 5 (modified forms)

Elliptical

The elliptical buoy turns out to have no utility for a 2000-foot design. The most efficient performance for a shape emulating a sphere was only 17%. At a height/diameter ratio of only 1:1.6 negative buoyancy occurs and becomes -34% at a ratio of 1:2.6.

Acceptability factor — 0

Torrodial

Torus shapes are quite attractive for the small material thickness required according to the calculations, as well as the very high calculated efficiency values ranging to more than 80%. However, authorities (Szilard, 1973) warn that buckling at higher pressure regimes is evident and prediction is beyond the realm of linear equations. Several attributes combine to make the torroidal configuration desirable for array applications, including the latitude available in choosing a loading point and internal space to house accessory items. Development and testing to achieve a 2000-foot serviceable design will be required.

Acceptability factor — 5

Torospherical

As with the findings of the elliptical buoy shape, the torosphere offers no useful buoyancy in the flattened configurations. Negative buoyancy is achieved at a height-to-diameter ratio of about 1:1.7. Use of the remaining profiles will not offer any incentive in the reduction of form drag.

Acceptability factor — 0

OTHER STRUCTURES

Compound Buoy Assembly

The compound buoy as proposed in the accompanying text has a configuration roughly similar to the torroidal buoy at about double the packing factor. Incorporation of several spherical buoys supported by a structure precludes loss of the system due to a single failure at the cost of additional form drag and reduced efficiency. The arrangement also embodies space to house accessory items, and fairings may be used to improve form drag. Improvement of efficiency may be realized by adding shaped blocks of syntactic foam to void spaces within a fairing. The choice of fairing materials can be directed to those near neutral density in water.

Acceptability factor — 8

Glass Ball Assembly

The best feature of glass ball buoyancy is the demonstrated reliability to great depths. The worst facet affecting their consideration is the packing factor of about 10.4 pounds of buoyancy per cubic foot used. Structure to hold the balls in a desired configuration will both increase the form factor and somewhat reduce the efficiency. Considered as a solution to the need for buoyancy at a depth of 2000 feet, the glass ball approach is definitely an overkill.

Acceptability factor — 5

Syntactic Foam Constructions

In general, the complexion of the syntactic foam industry has been changed considerably in the last 2 years by the removal of traditional materials from the marketplace for ecological and safety considerations. Much research has been invested by foam marketers since that time to reconstruct the product line. Tables 2 and 3 show the total inventory of materials that could be considered for array buoyancy at the present time. For the target service depth of the array subsurface buoy at 2000 feet, at least one material is available for bulk casting of a float system at an efficiency near 50% and a cost of around $5 per pound of buoyancy.

The most significant factor in favor of syntactic foam designs is the freedom of failure due to handling abuse; that is, impacts that would dent a shell and provide the stress riser point for future failure would cause no more than local loss of buoyancy material if inflicted upon a shape of syntactic foam. The most prevalent objection to the use of foam, aside from cost of formulations for very deep water, is the property of water absorption. This could range from 2 to 5% by volume, but can be predicted and accommodated in a specific design.

Precast Buoy With GRP External Skin

The commercially manufactured disk buoy of syntactic foam provides a net buoyancy about 20% smaller than the target value used as the model for calculations in this paper, but otherwise

the product satisfies all the subsurface buoy criteria set forth except accommodation of accessories within the envelope. Since the shape is cast in two halves and bonded together as two disks face to face, a custom assembly could provide the needed spaces accessible around the perimeter of the shape.

Acceptability factor — 8

User-cast Foam in Shell

The end product to be realized from this approach will be similar in properties to the two categories discussed above and offers the ability to incorporate desired features in a system approaching the volumetric efficiency of a formed shell void, but eliminating the risk of implosion or slow flooding associated with the use of a pressure-resisting void. The shell containing the syntactic foam material may be formed in the shape of any of the void descriptions derived in the last section of this report and can be fabricated from a wide spectrum of materials.

Acceptability factor — 9

Assembly of Precast Blocks

Precast blocks of syntactic foam are offered for service at depth from 6000 to 24,000 feet, all of which are an overkill for the intended service depth of 2000 feet. The only remaining argument in favor of precast blocks is the convenience of assembly of buoyancy material in the shortest possible time, presuming of course that the vendor can supply the material at short notice. Precast blocks can be produced with the highest level of quality control and pre-testing of any formulation.

Acceptability factor — 3

FLUID-FILLED BUOY SYSTEMS

Gas-inflated Devices

The target service depth of 2000 feet for the array subsurface buoy translates to 60 atmospheres as the operating pressure regime. Correspondingly, a gas supply system must be prepared to supply the working fluid at that pressure. This consideration will certainly relegate any consideration of gas-based systems to the role of emergency recovery or salvage. A system designed to provide useful lift at the stated 2000 feet will become nonfunctional if the design depth is exceeded for any reason, such as the loss of the primary buoyancy system.

Compressed Gas Reservoir

Each 1000 pounds of useful lift will require about 20 cubic feet of gas at the above stated 60 atmospheres. If the containing vessel is limited to 2000 psi in an environment of one atmosphere, a minimum of 225 cubic feet of gas storage will be needed. That is a cube 6.1 feet on a side.

Gas Generating Device

No data are available for this paper to predict the potential of chemical reaction gas generation for buoyancy requirements. Many issues would have to be addressed to produce a workable system for array service.

Liquid-filled Systems

Several fluids less dense than seawater are available for consideration as a buoyancy medium. All are incompressible for practical purposes and could be considered as free-form buoyancy material. Some are fairly active solvents and others are soluble in seawater. Some are toxic or must be considered pollutants for various properties.

The solvent properties are difficult to contain in a pliant envelope which is self-compensating for the pressure gradient. Toxic materials are to be avoided in all but the most urgent applications, considering potential danger to personnel and environmental impact associated with a loss of material. Pollutant materials will require careful and durable packaging.

Rigid Shell Container

Rigid shells must be compensated to accommodate excursions of pressure regime. Compressibility, dissolved gas, and imperfect filling all must be accounted for in the design and construction of

a rigid shell to contain the buoyant fluid. Strength must be equal to all the abuse that handling tasks will impose on the structure. Additionally, protection of the shell from deterioration by corrosion will be essential to mission success as well as avoidance of environmental disaster. These considerations in opposition to a need for minimum structural weight make the rigid shell seem to be a poor choice for a long-term mission assignment.

Acceptability factor — 4

Rigid Shell With Liner

This approach can provide several features lacking above, including self-compensation, choice of outer shape, imperviousness to handling damage, and compatibility with the medium used for buoyancy. Deterioration of the containing shell by corrosion or minor damage can be withstood better than the shell alone.

Acceptability factor — 7

Bladder Without Shell

A flexible bladder has no compensation problem, but is vulnerable to handling and environmental damage, not the least of which is biological attack "fishbite" and other curious critters boring out a dwelling place. Stress concentrations on the bladder surface caused by the loading of attachment points could induce tearing after prolonged service. Handling of an inflated or partially inflated bladder can be most frustrating as well. Even the super durable fuel transportation bladders, aside from their weight, are probably vulnerable to chafing and fishbite.

Acceptability factor — 5

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APPENDIX A

CALCULATIONS OF THE PARAMETERS FOR CYLINDRICAL BUOYS

Part A.1
Single Buoy Configurations, including
Flat End Plates
Hemispherical End Bells
Elliptical End Bells (2 cases)
Torospherical End Bells (1 case)
Dished and Flanged End Bells (1 case)

1. Calculations for a Single Cylindrical Buoy with Flat Plate End Closures

SuperCalc ver. 2.1

COL	SYMB	EXPRESSION	DESCRIPTION	UNITS	EQUATION
A	D_g	= 1000	Buoy Gross Displacement	lb	assigned
B	V_s	= A12/64.3	Buoy Volume	cu ft	D_g / 64.3
C	D	= (4*B12/PI)^(1/3)	Buoy Diameter	ft	$(4\ V_s / \pi)^{1/3}$
D	L_b	= C12	Buoy Length	ft	D
E	R	= C12/2	Buoy Radius	ft	D / 2
F	A	= PI*E12^2	Area of Cross Section	sq ft	πR^2
G	A_w	= PI*C12*D12	Cylinder Surface Area	sq ft	π R L
H	A_e	= 2*F12	Area of Ends	sq ft	2 A
I	D_w	= 2000	Working Depth	ft	assigned
J	P	= .446*I12	Working Pressure	psi	0.446 D_w
K	S_a	= 24000	Material Allowable Stress	psi	assigned
L	t_c	= 12*G12*E12/(K12+(.4*J12))	Cylinder Wall Thickness	in	12 P R / (S_a + (0.4 P))
M	m	= 1 / .27	Stress Calc Factor	-	1 / v
N	t_e	= (3*J12*G12*(M12+1)*144/8/PI/M12/K12)^.5	End Plate Thickness	in	$(3\ P\ A_e\ (m + 1)\ 144 / 8\ \pi\ m\ S_a)^{1/2}$
O	W_c	= G12*L12*40.8	Cylinder Wall Weight	lb	40.8 A_w t_c
P	W_e	= 2*F12*N12*40.8	End Plates Weight	lb	2 A_e 40.8 t_e
Q	W_b	= O12+P12	Total Buoy Weight	lb	$W_c + W_e$
R	B	= A12-Q12	Net Buoyancy	lb	D_g - B
S	E	= 100-((A12-R12)/A12*100)	Efficiency	%	100 - (100 ((D_g - B) / D_g)

Calculations for Single Cylindrical Buoy, Flat End Closure

Gross Displace-ment Dg lb	Buoy Volume Vb cu ft	Buoy Diameter D ft	Buoy Length (L = D) Lb ft	Buoy Radius R ft	Area of Cross Section A sq ft	Cylinder Surface Area Asc sq ft	Sum Ends Surface Area Ae sq ft	Buoy Working Depth Db ft	Buoy Working Pressure P psi	Material Allowable Stress Sa psi	Material thickness Cylinder tc in	Stress calc factor (1/nu) m -	Material thickness ends te in
200	3.110420	1.582133	1.582133	.7910666	1.965966	7.863864	3.931932	2000	892	24000	.3476473	3.703704	1.262957
500	7.776050	2.147285	2.147285	1.073643	3.621340	14.48536	7.242680	2000	892	24000	.4718300	3.703704	1.714096
700	10.88647	2.402144	2.402144	1.201072	4.531980	18.12792	9.063960	2000	892	24000	.5278311	3.703704	1.917541
1000	15.55210	2.705410	2.705410	1.352705	5.748519	22.99408	11.49704	2000	892	24000	.5944686	3.703704	2.159626
1200	18.66252	2.874927	2.874927	1.437463	6.491476	25.96591	12.98295	2000	892	24000	.6317172	3.703704	2.294945
1500	23.32815	3.096921	3.096921	1.548461	7.532691	30.13076	15.06538	2000	892	24000	.6804967	3.703704	2.472155
1700	26.43857	3.228861	3.228861	1.614431	8.188203	32.75281	16.37641	2000	892	24000	.7094883	3.703704	2.577478
2000	31.10420	3.408603	3.408603	1.704301	9.125205	36.50082	18.25041	2000	892	24000	.7489835	3.703704	2.720959
5000	77.76050	4.626186	4.626186	2.313093	16.80877	67.23509	33.61754	2000	892	24000	1.016527	3.703704	3.692909
7000	108.8647	5.175263	5.175263	2.587631	21.03559	84.14236	42.07118	2000	892	24000	1.137178	3.703704	4.131216
10000	155.5210	5.828629	5.828629	2.914314	26.68226	106.7290	53.36452	2000	892	24000	1.280744	3.703704	4.652774
12000	186.6252	6.193842	6.193842	3.096921	30.13076	120.5231	60.26153	2000	892	24000	1.360993	3.703704	4.944310
15000	233.2815	6.672114	6.672114	3.336057	34.96365	139.8546	69.92731	2000	892	24000	1.466086	3.703704	5.326096
17000	264.3857	6.956370	6.956370	3.478185	38.00627	152.0251	76.01254	2000	892	24000	1.528546	3.703704	5.553007
20000	311.0420	7.343612	7.343612	3.671806	42.35545	169.4218	84.71090	2000	892	24000	1.613636	3.703704	5.862128
22000	342.1462	7.580664	7.580664	3.790332	45.13406	180.5363	90.26813	2000	892	24000	1.665724	3.703704	6.051358
25000	388.8025	7.910666	7.910666	3.955333	49.14915	196.5966	98.29829	2000	892	24000	1.738237	3.703704	6.314785

Cylinder Weight Wc lb	Ends Weight Sum We lb	Buoy Weight Total Wb lb	Net Buoy-ancy B lb	Effic-iency E %
111.5411	202.6071	314.1483	-114.148	-57.07
278.8528	506.5178	785.3707	-285.371	-57.07
390.3940	709.1250	1099.519	-399.519	-57.07
557.7057	1013.036	1570.741	-570.741	-57.07
669.2468	1215.643	1884.890	-684.890	-57.07
836.5585	1519.554	2356.112	-856.112	-57.07
948.0996	1722.161	2670.260	-970.260	-57.07
1115.411	2026.071	3141.483	-1141.48	-57.07
2788.528	5065.178	7853.707	-2853.71	-57.07
3903.940	7091.250	10995.19	-3995.19	-57.07
5577.057	10130.36	15707.41	-5707.41	-57.07
6692.468	12156.43	18848.90	-6848.90	-57.07
8365.585	15195.54	23561.12	-8561.12	-57.07
9480.996	17221.61	26702.60	-9702.60	-57.07
11154.11	20260.71	31414.83	-11414.8	-57.07
12269.52	22286.78	34556.31	-12556.3	-57.07
13942.64	25325.89	39268.53	-14268.5	-57.07

* Roark, 4th ed., pg 298, case 1.

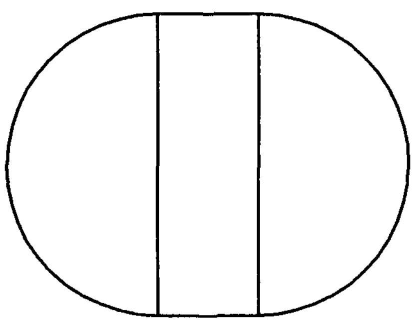
** Roark, 4th ed. pg 216, case 1.

Expressions for the Calculation of Parameters for Cylindrical Buoy with Hemipsherical End Bells

SuperCalc ver. 2.1

COL	SYMB	EXPRESSION	DESCRIPTION	UNITS	EQUATION
A	D_g	= 1000	Buoy Gross Displacement	lb	assigned
B	V_b	= A12/64.3	Buoy Volume	cu ft	D_g / 64.3
C	D	= (4*B12/PI)^(1/3)	Buoy Diameter	ft	$(4 V_b / \pi)^{1/3}$
D	R	= C12/2	End Bell Radius	ft	D / 2
E	V_e	= 4/3*PI*D12^3	End Bells Volume	cu ft	$4 \pi R^3 / 3$
F	V_c	= B12-E12	Cylinder Volume	cu ft	$V_b - V_e$
G	d_w	= 2000	Working Depth	ft	assigned
H	S_a	= 24000	Material Allowable Stress	psi	assigned
I	L_c	= F12/PI/D12^2	Buoy Cylindrical Length	ft	$V_c / \pi R^2$
J	L_b	= I12+C12	Buoy Total Length	ft	$L_c + D$
K	t_e	= 12*G12*.446*D12/((2*H12)+(.8*G12*.446))	End Bell Thickness	in	$12 P R / (2 S_a + 0.8 P)$
L	t_c	= G12*.446*D12*12/((2*H12)+.4*G12*.446)	Cylinder Wall Thickness	in	$12 P R / (S_a + 0.4 P)$
M	A_e	= 4*PI*D12^2	End Bells Surface Area	sq ft	$4 \pi R^2$
N	A_c	= PI*C12*I12	Cylinder Surface Area	sq ft	$\pi D L_c$
O	A_{bs}	= M12+N12	Total Buoy Surface Area	sq ft	$A_e + A_c$
P	W_b	= (40.8*K12*M12)+(40.8*L12*N12)	Weight of End Bells and Cylinder	lb	$40.8 t_e A_e + 40.8 t_c A_c$
Q	B	= A12-P12	Net Buoyancy	lb	$D_g - W_b$
R	E	= 100-((A12-Q12)/A12*100)	Efficiency	%	$100 - (100 (D_g - B) / D_g)$

CYLINDRICAL BUOY WITH HEMISPHERICAL END BELLS
BASED ON DIAMETER OF 1:1 BUOY WITH FLAT ENDS



Spreadsheet to Calculate the Parameters of Cylindrical Buoy with Hemispherical End Bells.

17 Aug 1990

Gross Displ-acement Dg pounds	Buoy Volume Vb cu ft	Cylinder Diameter D ft	cyl radius R ft	End Bells Volume Ve cu ft	Cyl Sect. Volume Vc cu ft	Buoy Work'g Depth d ft	Allowable Stress material Sa psi	Cylinder Adjusted Length L ft	Buoy final Length Lf ft	End Bell Thickn's te in	Cyl Wall Thickn's tc in	Surface Area Bells Ase sq ft	Surface Area Cyl Asc sq ft
1000	15.55210	2.705410	1.352705	10.36807	5.184033	2000	24000	.9018032	3.607213	.2972343	.2994274	22.99408	7.664692
2000	31.10420	3.408603	1.704301	20.73613	10.36807	2000	24000	1.136201	4.544804	.3744918	.3772549	36.50082	12.16694
5000	77.76050	4.626186	2.313093	51.84033	25.92017	2000	24000	1.542062	6.168247	.5082635	.5120137	67.23509	22.41170
7000	108.8647	5.175263	2.587631	72.57646	36.28823	2000	24000	1.725088	6.900350	.5685888	.5727841	84.14236	28.04745
10000	155.5210	5.828629	2.914314	103.6807	51.84033	2000	24000	1.942876	7.771505	.6403719	.6450969	106.7290	35.57635
12000	186.6252	6.193842	3.096921	124.4168	62.20840	2000	24000	2.064614	8.258456	.6804967	.6855177	120.5231	40.17435
15000	233.2815	6.672114	3.336057	155.5210	77.76050	2000	24000	2.224038	8.896152	.7330428	.7384516	139.8546	46.61821
17000	264.3857	6.956370	3.478185	176.2571	88.12856	2000	24000	2.318790	9.275160	.7642731	.7699123	152.0251	50.67503
20000	311.0420	7.343612	3.671806	207.3613	103.6807	2000	24000	2.447871	9.791482	.8068180	.8127711	169.4218	56.47393
22000	342.1462	7.580664	3.790332	228.0975	114.0487	2000	24000	2.526888	10.10755	.8328622	.8390075	180.5363	60.17875
25000	388.8025	7.910666	3.955333	259.2017	129.6008	2000	24000	2.636889	10.54755	.8691184	.8755312	196.5966	65.53220

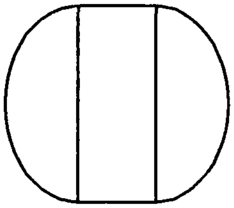
Buoy Surface Area As sq ft	Buoy Weight W pounds	Net Buoyancy B pounds	Efficiency E %
30.65877	372.4896	627.5104	62.75
48.66776	744.9792	1255.021	62.75
89.64678	1862.448	3137.552	62.75
112.1898	2607.427	4392.573	62.75
142.3054	3724.896	6275.104	62.75
160.6974	4469.875	7530.125	62.75
186.4728	5587.344	9412.656	62.75
202.7001	6332.323	10667.68	62.75
225.8957	7449.792	12550.21	62.75
240.7150	8194.772	13805.23	62.75
262.1288	9312.240	15687.76	62.75

Calculation of Expressions for the Parameters of a Cylindrical Buoy. Presented in Two Parts with Eight Cases.

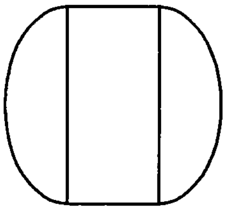
SuperCalc ver. 2.1

COL	SYMB	EXPRESSION	DESCRIPTION	UNITS	EQUATION
A	D_g	= 1000	Buoy Gross Displacement	lb	assigned
B	V_b	= A13/64.3	Buoy Volume	cu ft	D_g / 64.3
C	D	= (4*B13/PI)^(1/3)	Buoy Diameter	ft	$(4\ V_b / \pi)^{1/3}$
D	L_n	= C13	Buoy Nominal Length	ft	D
E	R	= C13/2	End Bell Major Semi-axis	ft	D / 2
F	a	= 1.2	End Bell Diameter : Height ratio	-	assigned
G	H	= E13/F13	End Bell Minor Semi-axis	ft	D / a
H	V_e	= 4/3*PI*E13^2*G13	End Bell Volume	cu ft	$4\ \pi\ R^2\ H / 3$
I	V_c	= B13-H13	Volume of Cylinder Section	cu ft	$V_b - V_e$
J	d	= 2000	Working Depth	ft	assigned
K	S_a	= 24000	Material Allowable Stress	psi	assigned
L	L_c	= 4*I13/PI/C13^2	Cylinder Actual Length	ft	$4\ V_c / \pi\ D^2$
M	L_t	= L13+(2*G13)	Buoy Total Length	ft	$L_c + 2\ H$
N	t_e	= J13*.446*C13*12/(2*K13+(1.8*J13*.446))	End Bell Thickness	in	$12\ P\ D / (2\ S_a + 1.8\ P)$ $P = .446\ d$
O	t_c	= J13*.446*E13*12/(K13+(.4*J13*.446))	Cylinder Wall Thickness	in	$12\ P\ R / (S_a + 0.4\ P)$
P	e	= (E13^2-G13^2)^.5/E13	End Bell Eccentricity	-	$(R^2 - H^2)^{1/2} / R$
Q	A_{se}	= 2*PI*E13^2+(PI*G13^2/P13*LN((1+P13)/(1-P13)))	End Bells Surface Area	sq ft	$2\ \pi\ R^2 + \pi\ H^2 / e\ \ln((1 + e) / (1 - e))$
R	A_{sc}	= PI*C13*L13	Cylinder Surface Area	sq ft	$\pi\ D\ L_c$
S	A_{st}	= Q13+R13	Buoy Total Surface Area	sq ft	$A_{se} + A_{sc}$
T	W_e	= 40.8*N13*Q13	Weight of End Bells	lb	$40.8\ t_e\ A_{se}$
U	W_c	= 40.8*O13*R13	Weight of Cylinder Section	lb	$40.8\ t_c\ A_{sc}$
V	W_t	= T13+U13	Buoy Total Weight	lb	$W_e + W_c$
W	B	= A13-V13	Net Buoyancy	lb	$D_g - B$
X	E	= 100-((A13-W13)/A13*100)	Efficiency	%	$100 - (100\ (D_g - B) / D_g)$
Z	A_f	= PI*C13*L13+(PI*E13*G13)	Buoy Frontal Area	sq ft	$\pi\ D\ L_c + \pi\ R\ H$

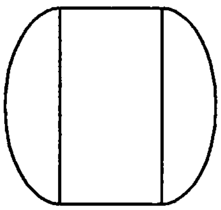
CYLINDRICAL BUOYS WITH SEMIELLIPTICAL END BELLS



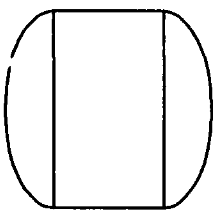
CASE 1
a = 1.2



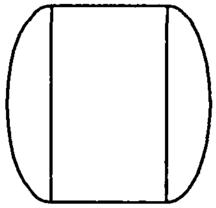
CASE 2
a = 1.4



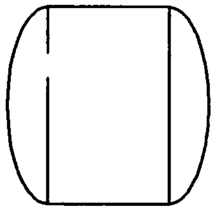
CASE 3
a = 1.6



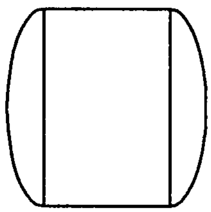
CASE 4
a = 1.8



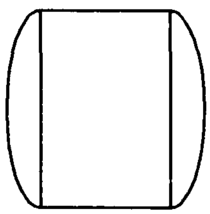
CASE 5
a = 2.0



CASE 6
a = 2.2



CASE 7
a = 2.4



CASE 8
a = 2.6

Spreadsheet to Calculate the Properties of Cylindrical Buoys with Semielliptical End Bells
17 Aug 1990 for a range of bell height ratios

Gross Displac-ement	Buoy Volume	Buoy Diameter	Buoy nominal Length	Buoy Radius	End Bell Height Ratio	Bell minor semi-axis	Volume end bells	Volume Cylind-der	Working Depth	Allowable Stress	Cylinder Wall Length	Buoy Total Length	End Bell Thickn's
Dg pounds	Vb cu ft	D ft	Lb ft	R ft	a	H ft	Ve cu ft	Vc cu ft	d ft	Sa psi	Lc ft	Lb ft	te in
CASE 1:													
1000	15.55210	2.705410	2.705410	1.352705	1.2	1.127254	8.640055	6.912044	2000	24000	1.202404	3.456912	.5837790
2000	31.10420	3.408603	3.408603	1.704301	1.2	1.420251	17.28011	13.82409	2000	24000	1.514935	4.355437	.7355154
5000	77.76050	4.626186	4.626186	2.313093	1.2	1.927577	43.20028	34.56022	2000	24000	2.056082	5.911237	.9982480
7000	108.8647	5.175263	5.175263	2.587631	1.2	2.156359	60.48039	48.38431	2000	24000	2.300117	6.612836	1.116729
10000	155.5210	5.828629	5.828629	2.914314	1.2	2.428595	86.40055	69.12044	2000	24000	2.590502	7.447692	1.257714
12000	186.6252	6.193842	6.193842	3.096921	1.2	2.580768	103.6807	82.94453	2000	24000	2.752819	7.914354	1.336520
15000	233.2815	6.672114	6.672114	3.336057	1.2	2.780048	129.6008	103.6807	2000	24000	2.965384	8.525479	1.439723
17000	264.3857	6.956370	6.956370	3.478185	1.2	2.898488	146.8809	117.5048	2000	24000	3.091720	8.888695	1.501060
20000	311.0420	7.343612	7.343612	3.671806	1.2	3.059838	172.8011	138.2409	2000	24000	3.263827	9.383504	1.584620
22000	342.1462	7.580664	7.580664	3.790332	1.2	3.158610	190.0812	152.0650	2000	24000	3.369184	9.686405	1.635772
25000	388.8025	7.910666	7.910666	3.955333	1.2	3.296111	216.0014	172.8011	2000	24000	3.515852	10.10807	1.706980
CASE 2:													
1000	15.55210	2.705410	2.705410	1.352705	1.4	.9662178	7.405762	8.146338	2000	24000	1.417119	3.349555	.5837790
2000	31.10420	3.408603	3.408603	1.704301	1.4	1.217358	14.81152	16.29268	2000	24000	1.785459	4.220175	.7355154
5000	77.76050	4.626186	4.626186	2.313093	1.4	1.652209	37.02881	40.73169	2000	24000	2.423240	5.727658	.9982480
7000	108.8647	5.175263	5.175263	2.587631	1.4	1.848308	51.84033	57.02436	2000	24000	2.710852	6.407468	1.116729
10000	155.5210	5.828629	5.828629	2.914314	1.4	2.081653	74.05762	81.46338	2000	24000	3.053091	7.216397	1.257714
12000	186.6252	6.193842	6.193842	3.096921	1.4	2.212086	88.86914	97.75605	2000	24000	3.244393	7.668566	1.336520
15000	233.2815	6.672114	6.672114	3.336057	1.4	2.382898	111.0864	122.1951	2000	24000	3.494917	8.260713	1.439723
17000	264.3857	6.956370	6.956370	3.478185	1.4	2.484418	125.8979	138.4877	2000	24000	3.643813	8.612649	1.501060
20000	311.0420	7.343612	7.343612	3.671806	1.4	2.622719	148.1152	162.9268	2000	24000	3.846654	9.092091	1.584620
22000	342.1462	7.580664	7.580664	3.790332	1.4	2.707380	162.9268	179.2194	2000	24000	3.970824	9.385585	1.635772
25000	388.8025	7.910666	7.910666	3.955333	1.4	2.825238	185.1440	203.6584	2000	24000	4.143682	9.794158	1.706980
CASE 3:													
1000	15.55210	2.705410	2.705410	1.352705	1.6	.8454405	6.480041	9.072058	2000	24000	1.578156	3.269037	.5837790
2000	31.10420	3.408603	3.408603	1.704301	1.6	1.065188	12.96008	18.14412	2000	24000	1.988352	4.118728	.7355154
5000	77.76050	4.626186	4.626186	2.313093	1.6	1.445683	32.40021	45.36029	2000	24000	2.698608	5.589974	.9982480
7000	108.8647	5.175263	5.175263	2.587631	1.6	1.617270	45.36029	63.50441	2000	24000	3.018903	6.253442	1.116729
10000	155.5210	5.828629	5.828629	2.914314	1.6	1.821446	64.80041	90.72058	2000	24000	3.400033	7.042926	1.257714
12000	186.6252	6.193842	6.193842	3.096921	1.6	1.935576	77.76050	108.8647	2000	24000	3.613075	7.484226	1.336520
15000	233.2815	6.672114	6.672114	3.336057	1.6	2.085036	97.20062	136.0809	2000	24000	3.892067	8.062138	1.439723
17000	264.3857	6.956370	6.956370	3.478185	1.6	2.173866	110.1607	154.2250	2000	24000	4.057883	8.405614	1.501060
20000	311.0420	7.343612	7.343612	3.671806	1.6	2.294879	129.6008	181.4412	2000	24000	4.283774	8.873531	1.584620
22000	342.1462	7.580664	7.580664	3.790332	1.6	2.368958	142.5609	199.5853	2000	24000	4.422054	9.159970	1.635772
25000	388.8025	7.910666	7.910666	3.955333	1.6	2.472083	162.0010	226.8015	2000	24000	4.614555	9.558721	1.706980
CASE 4:													
1000	15.55210	2.705410	2.705410	1.352705	1.8	.7515027	5.760037	9.792063	2000	24000	1.703406	3.206412	.5837790
2000	31.10420	3.408603	3.408603	1.704301	1.8	.9468341	11.52007	19.58413	2000	24000	2.146157	4.039825	.7355154
5000	77.76050	4.626186	4.626186	2.313093	1.8	1.285052	28.80018	48.96031	2000	24000	2.912784	5.482887	.9982480
7000	108.8647	5.175263	5.175263	2.587631	1.8	1.437573	40.32026	68.54444	2000	24000	3.258499	6.133645	1.116729
10000	155.5210	5.828629	5.828629	2.914314	1.8	1.619063	57.60037	97.92063	2000	24000	3.669877	6.908004	1.257714
12000	186.6252	6.193842	6.193842	3.096921	1.8	1.720512	69.12044	117.5048	2000	24000	3.899827	7.340850	1.336520
15000	233.2815	6.672114	6.672114	3.336057	1.8	1.853365	86.40055	146.8809	2000	24000	4.200961	7.907691	1.439723
17000	264.3857	6.956370	6.956370	3.478185	1.8	1.932325	97.92063	166.4651	2000	24000	4.379937	8.244587	1.501060
20000	311.0420	7.343612	7.343612	3.671806	1.8	2.039892	115.2007	195.8413	2000	24000	4.623756	8.703540	1.584620
22000	342.1462	7.580664	7.580664	3.790332	1.8	2.105740	126.7208	215.4254	2000	24000	4.773011	8.984491	1.635772
25000	388.8025	7.910666	7.910666	3.955333	1.8	2.197407	144.0009	244.8016	2000	24000	4.980790	9.375604	1.706980

Cyl Wall Thickn's	ellipse eccen-tricity	End Bells Surface Area	Cylinder Surface Area	Total Surface Area	Weight End Bells	Weight Cyl Wall	Total Weight Buoy	Net Buoy-ancy	Effic-iency	Buoy Frontal Area
tc in	e	Ase sq ft	Asc sq ft	Asb sq ft	We pounds	Wc pounds	Wb pounds	B pounds	E %	Af sq ft
CASE 1: (conclusion)										
.5944686	.5527708	20.48625	10.21959	30.70584	487.9453	247.8692	735.8145	264.1855	26.42	15.01002
.7489835	.5527708	32.51990	16.22259	48.74249	975.8906	495.7384	1471.629	528.3710	26.42	23.82692
1.016527	.5527708	59.90217	29.88226	89.78443	2439.727	1239.346	3679.073	1320.927	26.42	43.88957
1.137178	.5527708	74.96547	37.39660	112.3621	3415.617	1735.084	5150.702	1849.298	26.42	54.92626
1.280744	.5527708	95.08877	47.43513	142.5239	4879.453	2478.692	7358.145	2641.855	26.42	69.67035
1.360993	.5527708	107.3783	53.56580	160.9442	5855.344	2974.430	8829.774	3170.226	26.42	78.67477
1.466086	.5527708	124.6015	62.15761	186.7591	7319.180	3718.038	11037.22	3962.782	26.42	91.29399
1.528546	.5527708	135.4446	67.56670	203.0113	8295.070	4213.776	12508.85	4491.153	26.42	99.23860
1.613636	.5527708	150.9440	75.29858	226.2426	9758.906	4257.384	14716.29	5283.710	26.42	110.5948
1.665724	.5527708	160.8463	80.23833	241.0846	10734.80	5453.122	16187.92	5812.081	26.42	117.8501
1.738237	.5527708	175.1550	87.37626	262.5313	12198.63	6196.730	18395.36	6604.637	26.42	128.3339
CASE 2: (conclusion)										
.5944686	.6998542	18.76393	12.04452	30.80845	446.9227	292.1315	739.0543	260.9457	26.09	16.15060
.7489835	.6998542	29.78588	19.11948	48.90536	893.8455	584.2631	1478.109	521.8915	26.09	25.63748
1.016527	.6998542	54.86607	35.21838	90.08445	2234.614	1460.658	3695.271	1304.729	26.09	47.22464
1.137178	.6998542	68.66296	44.07457	112.7375	3128.459	2044.921	5173.380	1826.620	26.09	59.09999
1.280744	.6998542	87.09446	55.90569	143.0001	4469.227	2921.315	7390.543	2609.457	26.09	74.96445
1.360993	.6998542	98.35083	63.13112	161.4819	5363.073	3505.578	8868.651	3131.349	26.09	84.65310
1.466086	.6998542	114.1260	73.25718	187.3832	6703.841	4381.973	11085.81	3914.186	26.09	98.23122
1.528546	.6998542	124.0575	79.63219	203.6897	7597.687	4966.236	12563.92	4436.077	26.09	106.7795
1.613636	.6998542	138.2538	88.74475	226.9986	8938.455	5842.631	14781.09	5218.915	26.09	118.9986
1.665724	.6998542	147.3236	94.56661	241.8902	9832.300	6426.894	16259.19	5740.806	26.09	126.8052
1.738237	.6998542	160.4294	102.9792	263.4085	11173.07	7303.288	18476.36	6523.643	26.09	138.0857
CASE 3: (conclusion)										
.5944686	.7806247	17.52037	13.41321	30.93359	417.3034	325.3283	742.6318	257.3682	25.74	17.00604
.7489835	.7806247	27.81186	21.29215	49.10401	834.6069	650.6566	1485.264	514.7365	25.74	26.99540
1.016527	.7806247	51.22988	39.22047	90.45035	2086.517	1626.642	3713.159	1286.841	25.74	49.72595
1.137178	.7806247	64.11240	49.08304	113.1954	2921.124	2277.298	5198.422	1801.578	25.74	62.23028
1.280744	.7806247	81.32237	62.25861	143.5810	4173.034	3253.283	7426.318	2573.682	25.74	78.93503
1.360993	.7806247	91.83274	70.30512	162.1379	5007.641	3903.940	8911.581	3088.419	25.74	89.13684
1.466086	.7806247	106.5625	81.58186	188.1443	6259.552	4879.925	11139.48	3860.524	25.74	103.4341
1.528546	.7806247	115.8358	88.68130	204.5171	7094.159	5530.581	12624.74	4375.260	25.74	112.4352
1.613636	.7806247	129.0912	98.82939	227.9206	8346.069	6506.566	14852.64	5147.365	25.74	125.3015
1.665724	.7806247	137.5599	105.3128	242.8727	9180.676	7157.223	16337.90	5662.101	25.74	133.5216
1.738237	.7806247	149.7971	114.6813	264.4784	10432.59	8133.208	18565.79	6434.206	25.74	145.3996
CASE 4: (conclusion)										
.5944686	.8314794	16.58797	14.47775	31.06572	395.0953	351.1480	746.2433	253.7567	25.38	17.67137
.7489835	.8314794	26.33176	22.98200	49.31376	790.1906	702.2960	1492.487	507.5133	25.38	28.05156
1.016527	.8314794	48.50352	42.33320	90.83673	1975.477	1755.740	3731.217	1268.783	25.38	51.67141
1.137178	.8314794	60.70046	52.97852	113.6790	2765.667	2458.036	5223.703	1776.297	25.38	64.66496
1.280744	.8314794	76.99454	67.19977	144.1943	3950.953	3511.480	7462.433	2537.567	25.38	82.02325
1.360993	.8314794	86.94557	75.88489	162.8305	4741.144	4213.776	8954.920	3045.080	25.38	92.62420
1.466086	.8314794	100.8914	88.05661	188.9480	5926.430	5267.220	11193.65	3806.350	25.38	107.4809
1.528546	.8314794	109.6712	95.71950	205.3907	6716.620	5969.516	12686.14	4313.863	25.38	116.8341
1.613636	.8314794	122.2212	106.6730	228.8942	7901.906	7022.960	14924.87	5075.133	25.38	130.2038
1.665724	.8314794	130.2392	113.6710	243.9102	8692.097	7725.256	16417.35	5582.647	25.38	138.7455
1.738237	.8314794	141.8252	123.7830	265.6082	9877.383	8778.700	18656.08	6343.917	25.38	151.0881

Spreadsheet to Calculate the Properties of Cylindrical Buoys with Semielliptical End Bells
17 Aug 1990 for a range of bell height ratios

Gross Displac-ement Dg pounds	Buoy Volume Vb cu ft	Buoy Diameter D ft	Buoy nominal Length Lb ft	Buoy Radius R ft	End Bell Height Ratio a	Bell minor semi-axis H ft	Volume end bells Ve cu ft	Volume Cylind-der Vc cu ft	Working Depth d ft	Allowable Stress Sa psi	Cylinder Wall Length Lc ft	Buoy Total Length Lb ft	End Bell Thickn's te in
CASE 5:													
1000	15.55210	2.705410	2.705410	1.352705	2	.6763524	5.184033	10.36807	2000	24000	1.803606	3.156311	.5837790
2000	31.10420	3.408603	3.408603	1.704301	2	.8521507	10.36807	20.73613	2000	24000	2.272402	3.976703	.7355154
5000	77.76050	4.626186	4.626186	2.313093	2	1.156546	25.92017	51.84033	2000	24000	3.084124	5.397217	.9982480
7000	108.8647	5.175263	5.175263	2.587631	2	1.293816	36.28823	72.57646	2000	24000	3.450175	6.037806	1.116729
10000	155.5210	5.828629	5.828629	2.914314	2	1.457157	51.84033	103.6807	2000	24000	3.885752	6.800067	1.257714
12000	186.6252	6.193842	6.193842	3.096921	2	1.548461	62.20840	124.4168	2000	24000	4.129228	7.226149	1.336520
15000	233.2815	6.672114	6.672114	3.336057	2	1.668029	77.76050	155.5210	2000	24000	4.448076	7.784133	1.439723
17000	264.3857	6.956370	6.956370	3.478185	2	1.739093	88.12856	176.2571	2000	24000	4.637580	8.115765	1.501060
20000	311.0420	7.343612	7.343612	3.671806	2	1.835903	103.6807	207.3613	2000	24000	4.895741	8.567547	1.584620
22000	342.1462	7.580664	7.580664	3.790332	2	1.895166	114.0487	228.0975	2000	24000	5.053776	8.844109	1.635772
25000	388.8025	7.910666	7.910666	3.955333	2	1.977667	129.6008	259.2017	2000	24000	5.273777	9.229110	1.706980
CASE 6:													
1000	15.55210	2.705410	2.705410	1.352705	2.2	.6148658	4.712757	10.83934	2000	24000	1.885589	3.115320	.5837790
2000	31.10420	3.408603	3.408603	1.704301	2.2	.7746824	9.425515	21.67868	2000	24000	2.375693	3.925058	.7355154
5000	77.76050	4.626186	4.626186	2.313093	2.2	1.051406	23.56379	54.19671	2000	24000	3.224311	5.327123	.9982480
7000	108.8647	5.175263	5.175263	2.587631	2.2	1.176196	32.98930	75.87539	2000	24000	3.607001	5.959393	1.116729
10000	155.5210	5.828629	5.828629	2.914314	2.2	1.324688	47.12757	108.3934	2000	24000	4.062377	6.711754	1.257714
12000	186.6252	6.193842	6.193842	3.096921	2.2	1.407691	56.55309	130.0721	2000	24000	4.316920	7.132303	1.336520
15000	233.2815	6.672114	6.672114	3.336057	2.2	1.516390	70.69136	162.5901	2000	24000	4.650261	7.683041	1.439723
17000	264.3857	6.956370	6.956370	3.478185	2.2	1.580993	80.11688	184.2688	2000	24000	4.848379	8.010366	1.501060
20000	311.0420	7.343612	7.343612	3.671806	2.2	1.669003	94.25515	216.7868	2000	24000	5.118275	8.456280	1.584620
22000	342.1462	7.580664	7.580664	3.790332	2.2	1.722878	103.6807	238.4655	2000	24000	5.283493	8.729250	1.635772
25000	388.8025	7.910666	7.910666	3.955333	2.2	1.797879	117.8189	270.9836	2000	24000	5.513495	9.109252	1.706980
CASE 7:													
1000	15.55210	2.705410	2.705410	1.352705	2.4	.5636270	4.320028	11.23207	2000	24000	1.953907	3.081161	.5837790
2000	31.10420	3.408603	3.408603	1.704301	2.4	.7101256	8.640055	22.46414	2000	24000	2.461769	3.882020	.7355154
5000	77.76050	4.626186	4.626186	2.313093	2.4	.9637887	21.60014	56.16036	2000	24000	3.341134	5.268711	.9982480
7000	108.8647	5.175263	5.175263	2.587631	2.4	1.078180	30.24019	78.62450	2000	24000	3.737690	5.894049	1.116729
10000	155.5210	5.828629	5.828629	2.914314	2.4	1.214298	43.20028	112.3207	2000	24000	4.209565	6.638160	1.257714
12000	186.6252	6.193842	6.193842	3.096921	2.4	1.290384	51.84033	134.7849	2000	24000	4.473330	7.054098	1.336520
15000	233.2815	6.672114	6.672114	3.336057	2.4	1.390024	64.80041	168.4811	2000	24000	4.818749	7.598797	1.439723
17000	264.3857	6.956370	6.956370	3.478185	2.4	1.449244	73.44047	190.9452	2000	24000	5.024045	7.922533	1.501060
20000	311.0420	7.343612	7.343612	3.671806	2.4	1.529919	86.40055	224.6414	2000	24000	5.303720	8.363558	1.584620
22000	342.1462	7.580664	7.580664	3.790332	2.4	1.579305	95.04061	247.1056	2000	24000	5.474924	8.633535	1.635772
25000	388.8025	7.910666	7.910666	3.955333	2.4	1.648055	108.0007	280.8018	2000	24000	5.713259	9.009370	1.706980
CASE 8:													
1000	15.55210	2.705410	2.705410	1.352705	2.6	.5202711	3.987718	11.56438	2000	24000	2.011715	3.052257	.5837790
2000	31.10420	3.408603	3.408603	1.704301	2.6	.6555005	7.975436	23.12876	2000	24000	2.534602	3.845603	.7355154
5000	77.76050	4.626186	4.626186	2.313093	2.6	.8896511	19.93859	57.82191	2000	24000	3.439984	5.219286	.9982480
7000	108.8647	5.175263	5.175263	2.587631	2.6	.9952428	27.91402	80.95067	2000	24000	3.848272	5.838758	1.116729
10000	155.5210	5.828629	5.828629	2.914314	2.6	1.120890	39.87718	115.6438	2000	24000	4.334108	6.575889	1.257714
12000	186.6252	6.193842	6.193842	3.096921	2.6	1.191123	47.85261	138.7726	2000	24000	4.605677	6.987924	1.336520
15000	233.2815	6.672114	6.672114	3.336057	2.6	1.283099	59.81577	173.4657	2000	24000	4.961316	7.527513	1.439723
17000	264.3857	6.956370	6.956370	3.478185	2.6	1.337764	67.79120	196.5945	2000	24000	5.172686	7.848213	1.501060
20000	311.0420	7.343612	7.343612	3.671806	2.6	1.412233	79.75436	231.2876	2000	24000	5.460634	8.285101	1.584620
22000	342.1462	7.580664	7.580664	3.790332	2.6	1.457820	87.72979	254.4164	2000	24000	5.636904	8.552545	1.635772
25000	388.8025	7.910666	7.910666	3.955333	2.6	1.521282	99.69295	289.1095	2000	24000	5.882290	8.924854	1.706980

Cyl Wall Thickn's	ellipse eccen-tricity	End Bells Surface Area	Cylinder Surface Area	Total Surface Area	Weight End Bells	Weight Cyl Wall	Total Weight Buoy	Net Buoy-ancy	Effic-iency	Buoy Frontal Area
tc in	e	Ase sq ft	Asc sq ft	Asb sq ft	We pounds	Wc pounds	Wb pounds	B pounds	E %	Af sq ft
CASE 5: (conclusion)										
.5944686	.8660254	15.86790	15.32938	31.19729	377.9446	371.8038	749.7483	250.2517	25.03	18.20364
.7489835	.8660254	25.18872	24.33388	49.52260	755.8891	743.6076	1499.497	500.5033	25.03	28.89648
1.016527	.8660254	46.39803	44.82339	91.22142	1889.723	1859.019	3748.742	1251.258	25.03	53.22778
1.137178	.8660254	58.06550	56.09490	114.1604	2645.612	2602.626	5248.238	1751.762	25.03	66.61270
1.280744	.8660254	73.65228	71.15270	144.8050	3779.446	3718.038	7497.483	2502.517	25.03	84.49383
1.360993	.8660254	83.17133	80.34870	163.5200	4535.335	4461.645	8996.980	3003.020	25.03	95.41409
1.466086	.8660254	96.51178	93.23641	189.7482	5669.168	5577.057	11246.23	3753.775	25.03	110.7182
1.528546	.8660254	104.9105	101.3501	206.2605	6425.058	6320.664	12745.72	4254.278	25.03	120.3532
1.613636	.8660254	116.9157	112.9479	229.8636	7558.891	7436.076	14994.97	5005.033	25.03	134.1256
1.665724	.8660254	124.5856	120.3575	244.9431	8314.780	8179.683	16494.46	5505.536	25.03	142.9245
1.738237	.8660254	135.6687	131.0644	266.7330	9448.614	9295.094	18743.71	6256.291	25.03	155.6390
CASE 6: (conclusion)										
.5944686	.8907235	15.29840	16.02617	31.32458	364.3802	388.7039	753.0841	246.9159	24.69	18.63914
.7489835	.8907235	24.28470	25.43997	49.72467	728.7603	777.4079	1506.168	493.8318	24.69	29.58779
1.016527	.8907235	44.73280	46.86082	91.59362	1821.901	1943.520	3765.421	1234.579	24.69	54.50117
1.137178	.8907235	55.98154	58.64467	114.6262	2550.661	2720.928	5271.589	1728.411	24.69	68.20630
1.280744	.8907235	71.00890	74.38691	145.3958	3643.802	3887.039	7530.841	2469.159	24.69	86.51521
1.360993	.8907235	80.18632	84.00092	164.1872	4372.562	4664.447	9037.009	2962.991	24.69	97.69672
1.466086	.8907235	93.04798	97.47443	190.5224	5465.702	5830.559	11296.26	3703.738	24.69	113.3670
1.528546	.8907235	101.1452	105.9569	207.1[illegible]21	6194.463	6607.967	12802.43	4197.570	24.69	123.2325
1.613636	.8907235	112.7196	118.0819	230.8015	7287.603	7774.079	15061.68	4938.318	24.69	137.3343
1.665724	.8907235	120.1143	125.8283	245.9426	8016.363	8551.487	16567.85	5432.150	24.69	146.3438
1.738237	.8907235	130.7995	137.0219	267.8214	9109.504	9717.599	18827.10	6172.897	24.69	159.3624
CASE 7: (conclusion)										
.5944686	.9090593	14.83905	16.60683	31.44589	353.4393	402.7874	756.2267	243.7733	24.38	19.00205
.7489835	.9090593	23.55553	26.36170	49.91723	706.8786	805.5748	1512.453	487.5466	24.38	30.16387
1.016527	.9090593	43.38966	48.55867	91.94833	1767.196	2013.937	3781.134	1218.866	24.38	55.56233
1.137178	.9090593	54.30064	60.76948	115.0701	2474.075	2819.512	5293.587	1706.413	24.38	69.53431
1.280744	.9090593	68.87679	77.08209	145.9589	3534.393	4027.874	7562.267	2437.733	24.38	88.19970
1.360993	.9090593	77.77865	87.04443	164.8231	4241.272	4833.449	9074.721	2925.279	24.38	99.59891
1.466086	.9090593	90.25413	101.0061	191.2602	5301.589	6041.811	11343.40	3656.599	24.38	115.5743
1.528546	.9090593	98.10825	109.7959	207.9041	6008.468	6847.386	12855.85	4144.146	24.38	125.6318
1.613636	.9090593	109.3351	122.3602	231.6953	7068.786	8055.748	15124.53	4875.466	24.38	140.0083
1.665724	.9090593	116.5077	130.3873	246.8950	7775.665	8861.323	16636.99	5363.012	24.38	149.1932
1.738237	.9090593	126.8721	141.9864	268.8586	8835.982	10069.69	18905.67	6094.332	24.38	162.4652
CASE 8: (conclusion)										
.5944686	.9230769	14.46239	17.09816	31.56055	344.4677	414.7042	759.1719	240.8281	24.08	19.30913
.7489835	.9230769	22.95761	27.14164	50.09924	688.9355	829.4084	1518.344	481.6561	24.08	30.65133
1.016527	.9230769	42.28827	49.99532	92.28359	1722.339	2073.521	3795.860	1204.140	24.08	56.46023
1.137178	.9230769	52.92229	62.56739	115.4897	2411.274	2902.929	5314.204	1685.796	24.08	70.65800
1.280744	.9230769	67.12845	79.36263	146.4[illegible]1	3444.677	4147.042	7591.719	2408.281	24.08	89.62503
1.360993	.9230769	75.80435	89.61971	165.[illegible]	4133.613	4976.451	9110.063	2889.937	24.08	101.2085
1.466086	.9230769	87.96315	103.9945	191.[illegible]6	5167.016	6220.563	11387.58	3612.421	24.08	117.4420
1.528546	.9230769	95.61791	113.0443	208.[illegible]22	5855.951	7049.972	12905.92	4094.077	24.08	127.6621
1.613636	.9230769	106.5598	125.9803	232.5401	6889.355	8294.084	15183.44	4816.561	24.08	142.2709
1.665724	.9230769	113.5503	134.2449	247.7952	7578.290	9123.493	16701.78	5298.217	24.08	151.6042
1.738237	.9230769	123.6517	146.1872	269.8389	8611.693	10367.61	18979.30	6020.701	24.08	165.0907

Spreadsheet to Calculate the Parameters of a Cylindrical with Buoy with Torospherical End Bells

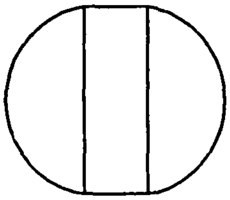
SuperCalc ver. 2.1

COL	SYMB	EXPRESSION	DESCRIPTION	UNITS	EQUATION
A	D_g	= 500	Buoy Gross Displacement	lb	assigned
B	V_b	= A13/64.3	Buoy Volume	cu ft	D_g / 64.3
C	D_b	= (4*B13/PI)^(1/3)	Buoy Diameter	ft	$(4\ V_b / \pi)^{1/3}$
D	a	= 2	Diameter : Height Aspect Ratio	-	assigned
E	f	= 6	Diameter : Flange Radius Aspect Ratio	-	assigned
F	d	= 2000	Working Depth	ft	assigned
G	S_a	= 24000	Material Allowable Stress	psi	assigned
H	W	= C13/2	End Bell Major Semi-axis	ft	$D_b / 2$
I	H	= C13/D13/2	End Bell Minor Semi-axis	ft	D_b / a
J	r	= C13/E13	Flange Radius	ft	D_b / f
K	w	= H13-J13	Flange Center Offset Radius	ft	$W - r$
L	h	= I13-J13	Crown Bulge Height	ft	$H - r$
M	ϕ_r	= 2*ATAN(L13/K13)	Crown Half Arc	radians	$2\ \mathrm{atan}(h / w)$
N	ϕ_d	= M13*180/PI	" " "	degrees	$180\ \phi_r / \pi$
O	θ_r	= PI/2-M13	Flange Arc	radians	$(\pi / 2) - \phi_r$
P	θ_d	= 90-N13	" "	degrees	$90 - \phi_d$
Q	R	= J13+K13/SIN(M13)	Crown Radius	ft	$r + w / \sin \phi$
R	C	= I13-J13*SIN(O13)	Crown Height	ft	$H - R \sin\theta$
S	V_c	= PI/3*R13^2*(3*Q13-R13)	Crown Volume	cu ft	$\pi C^2 (3 R - C) / 3$
T	V_f	= PI*(H13^2*I13*SIN(O13)-1/3*(J13*SIN(O13))^3)	Flange Disk Volume	cu ft	$\pi (W^2 r \sin\theta - (r \sin\theta)^3 / 3)$
U	V_e	= 2*(S13+T13)	End Bells Volume	cu ft	$2 (V_c + V_f)$
V	V_c	= B13-U13	Cylindrical Volume	cu ft	$V_b - V_e$
W	M	= (3+(Q13/J13)^.5)/4	Knuckle Stress Factor	-	$(3 + (R^2 / r^2)^{1/2} / 4$
X	T_e	= .446*F13*H13*W13*12/(2*G13+(446*F13*(W13-.2)))	End Bell Thickness	in	$12 P R M / (2 S_a + P (M - 0.2))$
Y	T_c	= .446*F13*H13*12/(G13+(.4*.446*F13))	Cylinder Wall Thickness	in	$P W / (S_a + 0.4 P)$ $P = .446 d$
Z	L_c	= V13/PI/H13^2	Cylinder Section Length	ft	$V_c / \pi W^2$
AA	l_1	= 2*PI*Q13*N13/360	End Bell Surface Calculation Parameter	ft	$2 \pi R \phi_d / 360$
AB	c_1	= 2*Q13*SIN(M13/2)	"	ft	$2 R \sin(\phi_r / 2)$
AC	d_1	= Q13*AB13/AA13	"	ft	$R c_1 / l_1$
AD	s_1	= AC13*SIN(M13/2)	"	ft	$d_1 \sin(\phi_r / 2)$
AE	l_2	= 2*PI*J13*P13/360	"	ft	$2 \pi r \theta_d / 360$
AF	c_2	= J13*SIN(O13/2)	"	ft	$r \sin(\theta_r / 2)$
AG	d_2	= J13*AF13/AE13	"	ft	$r c_2 / l_2$
AH	s_2	= AB13*COS(O13/2)+K13	"	ft	$d \cos(\theta_r / 2$
AI	X	= ((AA13*AD13)+(AE13*AH13))/(AA13+AE13)	Crown Profile CG Radius	ft	$((l_1 s_1) + (l_2 s_2)) / (l_1 + l_2)$

Spreadsheet to Calculate the Parameters of a Cylindrical with Buoy with Torospherical End Bells (continued)

COL	SYMB	EXPRESSION	DESCRIPTION	UNITS	EQUATION
AJ	A_{se}	= 4*PI*AI13*(AA13+AE13)	End Bells Surface Area	sq ft	$4 \pi X (l_1 + l_2)$
AK	A_{sc}	= PI*C13*Z13	Cylinder Section Surface Area	sq ft	$\pi D_b L_c$
AL	W_e	= AJ13*X13*40.8	Weight of Two End Bells	lb	$40.8\ t_e A_{se}$
AM	W_c	= AK13*Y13*40.8	Weight of Cylinder Wall	lb	$40.8\ t_c A_{sc}$
AN	W_b	= AL13+AM13	Total Buoy Weight	lb	$W_e + W_c$
AO	B	= A13-AN13	Net Buoyancy	lb	$D_s - W_b$
AP	E	= 100-(100*(A13-AO13)/A13)	Efficiency	%	$100 - (100 (D_s - B) / D_s)$
AR	W_t	= 5.1*(AJ13+AK13)	Weight of Thin Shell Construction (1/8 Plate)	lb	$5.1 (A_{se} + A_{sc})$

PROFILES OF CYLINDRICAL BUOYS WITH TOROSPHERICAL END BELLS

1

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f = 6.0

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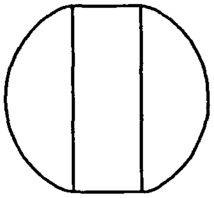
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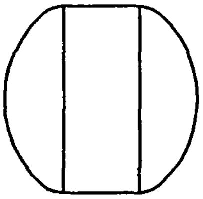
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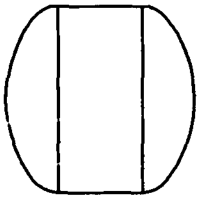
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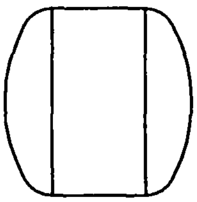
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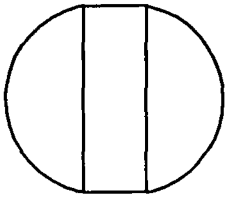
6

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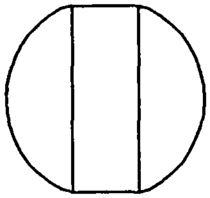
7

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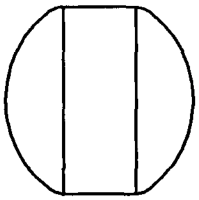
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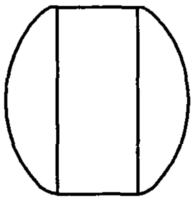
9

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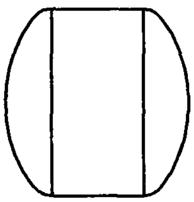
10

a = 2.0
f = 8.0

An AutoLisp Program Routine Created to Construct the Torospherical Outlines Shown on the Previous Page Is Reproduced Below.

```
(defun c:torodraw ()
; input data values
(setq  p1 (getpoint "\nPick a basepoint for the drawn shape: ")
     D (getreal "\nBuoy Diameter - 'D': ")
     A (getreal "\nHeight Ratio - 'a': ")
     F (getreal "\nFlange Ratio - 'f': ")
     R (getreal "\nCrown Radius - 'R': ")
); end setq

; calculate derived values
(setq  E (/ D 2)
     H (/ E A)
     S (/ E F)
     W (- E S)
     L (- R S)
     I (- R H)
     Theta (- (/ PI 2) (atan (/ w l)))
     x (* S (cos theta))
     y (* S (sin theta))
);end setq

; calculate construction points
(setq p1x (car p1)
     p1y (cadr p1)
     p2 (list (+ p1x E) p1y)
     p3 (list p1x (+ p1y H))
     p4 (list p1x (- p1y l))
     p5 (list (+ p1x W) p1y)
     p6 (list (+ p1x W x) (+ p1y y))
);end setq

; construct figure
(command "line" p1 p2 ""
     "arc" p2 "c" p5 p6 \r)
(command "arc" p6 "c" p4 p3 \r)
(command "mirror" "w" p3 p2 "" p1 p3 "n" \r
) ; end of drawing sequence

; install labels
(command "dtext" "c" (list p1x (- p1y 0.5)) 0.125 0 "A = !a" \r
     "F = !f" \r
);end text command
);end defun
```

Spreadsheet to Calculate the Parameters of a Cylindrical Buoy with Torospherical End Bells
27 July 1990

assign Gross Displa-cement lb Dg	Buoy Volume cu ft Vb	Buoy Diameter ft Db	assign Bell Height inverse Aspect ratio a	assign Bell Flange to Dia inverse ratio f	assign Working Depth ft d	assign Mat'l Allowable Stress ksi Sa	Buoy Major semi-axis ft W	Buoy Minor semi-axis ft H	** r MUST be less than H Flange Radius ft r	Flange Center Offset Radius ft w	Crown Bulge Height ft h	Crown half Arc rad phi(r)	Crown half Arc deg phi(d)
MODEL CALCULATION LINE			(1 - 4)	(2-30)									
500	7.776050	2.147285	2	6	2000	24000	1.073643	.5368213	.3578809	.7157617	.1789404	.4899573	28.07249
CASE 1:													
500	7.776050	2.147285	1.2	6	2000	24000	1.073643	.8947021	.3578809	.7157617	.5368213	1.287002	73.73980
1000	15.55210	2.705410	1.2	6	2000	24000	1.352705	1.127254	.4509016	.9018032	.6763524	1.287002	73.73980
2000	31.10420	3.408603	1.2	6	2000	24000	1.704301	1.420251	.5681004	1.136201	.8521507	1.287002	73.73980
7000	108.8647	5.175263	1.2	6	2000	24000	2.587631	2.156359	.8625438	1.725088	1.293816	1.287002	73.73980
10000	155.5210	5.828629	1.2	6	2000	24000	2.914314	2.428595	.9714381	1.942876	1.457157	1.287002	73.73980
12000	186.6252	6.193842	1.2	6	2000	24000	3.096921	2.580768	1.032307	2.064614	1.548461	1.287002	73.73980
15000	233.2815	6.672114	1.2	6	2000	24000	3.336057	2.780048	1.112019	2.224038	1.668029	1.287002	73.73980
17000	264.3857	6.956370	1.2	6	2000	24000	3.478185	2.898488	1.159395	2.318790	1.739093	1.287002	73.73980
20000	311.0420	7.343612	1.2	6	2000	24000	3.671806	3.059838	1.223935	2.447871	1.835903	1.287002	73.73980
22000	342.1462	7.580664	1.2	6	2000	24000	3.790332	3.158610	1.263444	2.526888	1.895166	1.287002	73.73980
25000	388.8025	7.910666	1.2	6	2000	24000	3.955333	3.296111	1.318444	2.636889	1.977667	1.287002	73.73980
CASE 2:													
500	7.776050	2.147285	1.4	6	2000	24000	1.073643	.7668875	.3578809	.7157617	.4090067	1.038292	59.48976
1000	15.55210	2.705410	1.4	6	2000	24000	1.352705	.9662178	.4509016	.9018032	.5153161	1.038292	59.48976
2000	31.10420	3.408603	1.4	6	2000	24000	1.704301	1.217358	.5681004	1.136201	.6492577	1.038292	59.48976
7000	108.8647	5.175263	1.4	6	2000	24000	2.587631	1.848308	.8625438	1.725088	.9857643	1.038292	59.48976
10000	155.5210	5.828629	1.4	6	2000	24000	2.914314	2.081653	.9714381	1.942876	1.110215	1.038292	59.48976
12000	186.6252	6.193842	1.4	6	2000	24000	3.096921	2.212086	1.032307	2.064614	1.179779	1.038292	59.48976
15000	233.2815	6.672114	1.4	6	2000	24000	3.336057	2.382898	1.112019	2.224038	1.270879	1.038292	59.48976
17000	264.3857	6.956370	1.4	6	2000	24000	3.478185	2.484418	1.159395	2.318790	1.325023	1.038292	59.48976
20000	311.0420	7.343612	1.4	6	2000	24000	3.671806	2.622719	1.223935	2.447871	1.398783	1.038292	59.48976
22000	342.1462	7.580664	1.4	6	2000	24000	3.790332	2.707380	1.263444	2.526888	1.443936	1.038292	59.48976
25000	388.8025	7.910666	1.4	6	2000	24000	3.955333	2.825238	1.318444	2.636889	1.506794	1.038292	59.48976
CASE 3:													
500	7.776050	2.147285	1.6	6	2000	24000	1.073643	.6710266	.3578809	.7157617	.3131457	.8248209	47.25876
1000	15.55210	2.705410	1.6	6	2000	24000	1.352705	.8454405	.4509016	.9018032	.3945389	.8248209	47.25876
2000	31.10420	3.408603	1.6	6	2000	24000	1.704301	1.065188	.5681004	1.136201	.4970879	.8248209	47.25876
7000	108.8647	5.175263	1.6	6	2000	24000	2.587631	1.617270	.8625438	1.725088	.7547258	.8248209	47.25876
10000	155.5210	5.828629	1.6	6	2000	24000	2.914314	1.821446	.9714381	1.942876	.8500083	.8248209	47.25876
12000	186.6252	6.193842	1.6	6	2000	24000	3.096921	1.935576	1.032307	2.064614	.9032686	.8248209	47.25876
15000	233.2815	6.672114	1.6	6	2000	24000	3.336057	2.085036	1.112019	2.224038	.9730166	.8248209	47.25876
17000	264.3857	6.956370	1.6	6	2000	24000	3.478185	2.173866	1.159395	2.318790	1.014471	.8248209	47.25876
20000	311.0420	7.343612	1.6	6	2000	24000	3.671806	2.294879	1.223935	2.447871	1.070943	.8248209	47.25876
22000	342.1462	7.580664	1.6	6	2000	24000	3.790332	2.368958	1.263444	2.526888	1.105514	.8248209	47.25876
25000	388.8025	7.910666	1.6	6	2000	24000	3.955333	2.472083	1.318444	2.636889	1.153639	.8248209	47.25876
CASE 4:													
500	7.776050	2.147285	1.8	6	2000	24000	1.073643	.5964681	.3578809	.7157617	.2385872	.6435011	36.86990
1000	15.55210	2.705410	1.8	6	2000	24000	1.352705	.7515027	.4509016	.9018032	.3006011	.6435011	36.86990
2000	31.10420	3.408603	1.8	6	2000	24000	1.704301	.9468341	.5681004	1.136201	.3787336	.6435011	36.86990
7000	108.8647	5.175263	1.8	6	2000	24000	2.587631	1.437573	.8625438	1.725088	.5750292	.6435011	36.86990
10000	155.5210	5.828629	1.8	6	2000	24000	2.914314	1.619063	.9714381	1.942876	.6476254	.6435011	36.86990
12000	186.6252	6.193842	1.8	6	2000	24000	3.096921	1.720512	1.032307	2.064614	.6882047	.6435011	36.86990
15000	233.2815	6.672114	1.8	6	2000	24000	3.336057	1.853365	1.112019	2.224038	.7413460	.6435011	36.86990
17000	264.3857	6.956370	1.8	6	2000	24000	3.478185	1.932325	1.159395	2.318790	.7729300	.6435011	36.86990
20000	311.0420	7.343612	1.8	6	2000	24000	3.671806	2.039892	1.223935	2.447871	.8159569	.6435011	36.86990
22000	342.1462	7.580664	1.8	6	2000	24000	3.790332	2.105740	1.263444	2.526888	.8422961	.6435011	36.86990
25000	388.8025	7.910666	1.8	6	2000	24000	3.955333	2.197407	1.318444	2.636889	.8789629	.6435011	36.86990
CASE 5:													
500	7.776050	2.147285	2	6	2000	24000	1.073643	.5368213	.3578809	.7157617	.1789404	.4899573	28.07249
1000	15.55210	2.705410	2	6	2000	24000	1.352705	.6763524	.4509016	.9018032	.2254508	.4899573	28.07249
2000	31.10420	3.408603	2	6	2000	24000	1.704301	.8521507	.5681004	1.136201	.2840502	.4899573	28.07249
7000	108.8647	5.175263	2	6	2000	24000	2.587631	1.293816	.8625438	1.725088	.4312719	.4899573	28.07249
10000	155.5210	5.828629	2	6	2000	24000	2.914314	1.457157	.9714381	1.942876	.4857190	.4899573	28.07249
12000	186.6252	6.193842	2	6	2000	24000	3.09692[illegible]	[illegible]48461	1.032307	2.064614	.5161535	.4899573	28.07249
15000	233.2815	6.672114	2	6	2000	24000	3.336057	[illegible]68029	1.112019	2.224038	.5560095	.4899573	28.07249
17000	264.3857	6.956370	2	6	2000	24000	3.478185	1.739093	1.159395	2.318790	.5796975	.4899573	28.07249
20000	311.0420	7.343612	2	6	2000	24000	3.671806	1.835903	1.223935	2.447871	.6119677	.4899573	28.07249
22000	342.1462	7.580664	2	6	2000	24000	3.790332	1.895166	1.263444	2.526888	.6317220	.4899573	28.07249
25000	388.8025	7.910666	2	6	2000	24000	3.955333	1.977667	1.318444	2.636889	.6592222	.4899573	28.07249

Spreadsheet to Calculate the Parameters of a Cylindrical Buoy with Torospherical End Bells (continued)
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Flange Arc Angle	Flange Arc Angle	Crown Radius	Crown Height	Crown Volume	Flange Volume	Volume End Bells	Volume Cylindrical Section	Knuckle Stress Correction factor	Thickness End Bell	Thickness Cylinder Wall	Length Cylinder Wall		
rad theta(r)	deg theta(d)	ft R	ft C	cu ft Vc	cu ft Vf	cu ft Ve	cu ft Vc	M	in te	in tc	ft Lc	ft l1	ft cl
MODEL CALCULATION LINE													
1.080839	61.92751	1.878874	.2210441	.2770966	1.682331	3.918856	3.857194	1.322822	.5429194	.4718300	1.06512[illegible]	.9205683	.9113880
CASE 1 (continued)													
.2837941	16.26020	1.103466	.7944955	1.663050	.9061521	5.138404	2.637646	1.188986	.2872970	.4718300	.7283618	1.420163	1.324159
.2837941	16.26020	1.390280	1.001002	3.326100	1.812304	10.27681	5.275291	1.188986	.3619716	.5944686	.9176783	1.789293	1.668336
.2837941	16.26020	1.751643	1.261183	6.652200	3.624608	20.55362	10.55058	1.188986	.4560556	.7489835	1.156202	2.254368	2.101972
.2837941	16.26020	2.659510	1.914847	23.28270	12.68613	71.93766	36.92704	1.188986	.6924267	1.137178	1.755455	3.422795	3.191412
.2837941	16.26020	2.995267	2.156593	33.26100	18.12304	102.7681	52.75291	1.188986	.7798441	1.280744	1.977078	3.854916	3.594321
.2837941	16.26020	3.182947	2.291722	39.91320	21.74765	123.3217	63.30350	1.188986	.8287080	1.360993	2.100959	4.096459	3.819536
.2837941	16.26020	3.428725	2.468682	49.89150	27.18456	154.1521	79.12937	1.188986	.8926986	1.466086	2.263189	4.412777	4.114470
.2837941	16.26020	3.574801	2.573857	56.54370	30.80917	174.7057	89.67995	1.188986	.9307308	1.528546	2.359609	4.600777	4.289762
.2837941	16.26020	3.773801	2.717136	66.52200	36.24608	205.5362	105.5058	1.188986	.9825420	1.613636	2.490962	4.856890	4.528561
.2837941	16.26020	3.895619	2.804846	73.17420	39.87069	226.0898	116.0564	1.188986	1.014259	1.665724	2.571371	5.013671	4.674743
.2837941	16.26020	4.065203	2.926946	83.15250	45.30761	256.9202	131.8823	1.188986	1.058411	1.738237	2.683308	5.231926	4.878244
CASE 2 (continued)													
.5325041	30.51024	1.188676	.5851942	1.068972	1.403662	4.945267	2.830782	1.205620	.3137166	.4718300	.7816947	1.234193	1.179497
.5325041	30.51024	1.497638	.7372985	2.137944	2.807324	9.890535	5.661565	1.205620	.3952581	.5944686	.9848736	1.554985	1.486073
.5325041	30.51024	1.886905	.9289379	4.275887	5.614647	19.78107	11.32313	1.205620	.4979940	.7489835	1.240863	1.959159	1.872334
.5325041	30.51024	2.864878	1.410401	14.96561	19.65127	69.23374	39.63095	1.205620	.7561016	1.137178	1.883995	2.974580	2.842755
.5325041	30.51024	3.226562	1.588651	21.37944	28.07324	98.90535	56.61565	1.205620	.8515578	1.280744	2.121846	3.350115	3.201646
.5325041	30.51024	3.428734	1.687992	25.65532	33.68788	118.6864	67.93878	1.205620	.9049152	1.360993	2.254798	3.560028	3.402257
.5325041	30.51024	3.693492	1.818334	32.06915	42.10986	148.3580	84.92347	1.205620	.9747904	1.466086	2.428907	3.834924	3.664970
.5325041	30.51024	3.850848	1.895802	36.34504	47.72450	168.1391	96.24660	1.205620	1.016320	1.528546	2.532387	3.998305	3.821111
.5325041	30.51024	4.065214	2.001336	42.75887	56.14647	197.8107	113.2313	1.205620	1.072896	1.613636	2.673358	4.220880	4.033822
.5325041	30.51024	4.196439	2.065939	47.03476	61.76112	217.5918	124.5544	1.205620	1.107529	1.665724	2.759655	4.357130	4.164034
.5325041	30.51024	4.379119	2.155874	53.44859	70.18309	247.2634	141.5391	1.205620	1.155742	1.738237	2.879788	4.546805	4.345303
CASE 3 (continued)													
.7459754	42.74124	1.332467	.4281370	.6851297	1.634218	4.638695	3.137354	1.232391	.3592996	.4718300	.8663518	1.099047	1.068156
.7459754	42.74124	1.678803	.5394188	1.370259	3.268436	9.277391	6.274709	1.232391	.4526891	.5944686	1.091535	1.384712	1.345792
.7459754	42.74124	2.115160	.6796251	2.740519	6.536872	18.55478	12.54942	1.232391	.5703525	.7489835	1.375248	1.744628	1.695592
.7459754	42.74124	3.211435	1.031871	9.591816	22.87905	64.94174	43.92296	1.232391	.8659030	1.137178	2.088031	2.648859	2.574408
.7459754	42.74124	3.616872	1.162143	13.70259	32.68436	92.77391	62.74709	1.232391	.9752890	1.280744	2.351640	2.983272	2.899421
.7459754	42.74124	3.843500	1.234961	16.44311	39.22123	111.3287	75.29650	1.232391	1.036399	1.360993	2.498991	3.170199	3.081095
.7459754	42.74124	4.140285	1.330321	20.55389	49.02654	139.1609	94.12063	1.232391	1.116427	1.466086	2.691956	3.414994	3.319009
.7459754	42.74124	4.316676	1.386998	23.29441	55.56341	157.7156	106.6700	1.232391	1.163991	1.528546	2.806643	3.560485	3.460410
.7459754	42.74124	4.556973	1.464208	27.40519	65.36872	185.5478	125.4942	1.232391	1.228787	1.613636	2.962881	3.758687	3.653042
.7459754	42.74124	4.704073	1.511473	30.14571	71.90559	204.1026	138.0436	1.232391	1.268453	1.665724	3.058523	3.880018	3.770962
.7459754	42.74124	4.908851	1.577270	34.25649	81.71090	231.9348	156.8677	1.232391	1.323671	1.738237	3.191667	4.048923	3.935120
CASE 4 (continued)													
.9272952	53.13010	1.550817	.3101634	.4374499	1.703435	4.281770	3.494280	1.270416	.4307819	.4718300	.9649136	.9979525	.9808228
.9272952	53.13010	1.953907	.3907814	.8748998	3.406870	8.563539	6.988560	1.270416	.5427511	.5944686	1.215715	1.257341	1.235759
.9272952	53.13010	2.461769	.4923537	1.749800	6.813740	17.12708	13.97712	1.270416	.6838236	.7489835	1.531705	1.584151	1.556959
.9272952	53.13010	3.737690	.7475379	6.124299	23.84809	59.94477	48.91992	1.270416	1.038246	1.137178	2.325579	2.405207	2.363923
.9272952	53.13010	4.209565	.8419130	8.748998	34.06870	85.63539	69.88560	1.270416	1.169322	1.280744	2.619178	2.708860	2.662363
.9272952	53.13010	4.473330	.8946661	10.49880	40.88244	102.7625	83.86272	1.270416	1.242590	1.360993	2.783292	2.878593	2.829183
.9272952	53.13010	4.818749	.9637498	13.12350	51.10305	128.4531	104.8284	1.270416	1.338539	1.466086	2.998211	3.100870	3.047645
.9272952	53.13010	5.024045	1.004809	14.87330	57.91679	145.5802	118.8055	1.270416	1.395566	1.528546	3.125945	3.232979	3.177485
.9272952	53.13010	5.303720	1.060744	17.49800	68.13740	171.2708	139.7712	1.270416	1.473253	1.613636	3.299958	3.412949	3.354367
.9272952	53.13010	5.474924	1.09498[illegible]	19.24780	74.95114	188.3979	153.7483	1.270416	1.520810	1.665724	3.406481	3.523120	3.462646
.9272952	53.13010	5.713259	1.142652	21.87250	85.17175	214.0885	174.7140	1.270416	1.587014	1.738237	3.554772	3.676488	3.613382
1.080839	61.92751	1.878874	.2210441	.2770966	1.682331	3.918856	3.857194	1.322822	.5429194	.4718300	1.065129	.9205683	.9113880
1.080839	61.92751	2.367234	.2784981	.5541932	3.364662	7.837711	7.714388	1.322822	.6840356	.5944686	1.341978	1.159843	1.148277
1.080839	61.92751	2.982527	.3508856	1.108386	6.729325	15.67542	15.42878	1.322822	.8618309	.7489835	1.690787	1.461311	1.446738
1.080839	61.92751	4.528355	.5327476	3.879353	23.55264	54.86398	54.00072	1.322822	1.308513	1.137178	2.567112	2.218701	2.196575
1.080839	61.92751	5.100050	.6000059	5.541932	33.64662	78.3771[illegible]	77.14388	1.322822	1.473710	1.280744	2.891205	2.498807	2.473888
1.080839	61.92751	5.419612	.6376014	6.650319	40.37595	94.052[illegible]3	92.57266	1.322822	1.566051	1.360993	3.072364	2.655379	2.628898
1.080839	61.92751	5.838100	.6868353	8.312899	50.46993	117.5657	115.7158	1.322822	1.686977	1.466086	3.309603	2.860420	2.831894
1.080839	61.92751	6.086824	.7160969	9.421285	57.19926	133.2411	131.1446	1.322822	1.758848	1.528546	3.450604	2.982284	2.952543
1.080839	61.92751	6.425660	.7559600	11.08386	67.29325	156.7542	154.2878	1.322822	1.856758	1.613636	3.642690	3.148299	3.116903
1.080839	61.92751	6.633081	.7803625	12.19225	74.02257	172.4296	169.7165	1.322822	1.916695	1.665724	3.760276	3.249927	3.217517
1.080839	61.92751	6.921833	.8143333	13.85483	84.11656	195.9428	192.8597	1.322822	2.000132	1.738237	3.923969	3.391403	3.357582

Spreadsheet to Calculate the Parameters of a Cylindrical Buoy with Torospherical End Bells (continued)
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ft d1	ft s1	ft l2	ft c2	ft d2	ft s2	Bell Profile CG Radius ft X	End Bells Surface Area sq ft Ase	Cylinder Surface Area sq ft Asc	Weight End Bells lb We	Weight Cylinder Wall lb Wc	Weight Complete Buoy lb Wb	Net Buoyancy lb B	Efficiency % E
MODEL CALCULATION LINE													
1.860138	.4511496	.3868116	.1841282	.1703567	1.497270	.7606631	12.49695	7.185248	276.8213	138.3208	415.1421	84.85786	16.97
CASE 1 (continued)													
1.028871	.6173226	.1015645	.0506120	.1783405	2.026612	.7113826	13.60348	4.913452	159.4562	94.58723	254.0434	245.9566	49.19
1.296296	.7777777	.1279632	.0637671	.2246950	2.553372	.8962859	21.59418	7.799619	318.9123	189.1745	508.0868	491.9132	49.19
1.633231	.9799385	.1612236	.0803415	.2830980	3.217047	1.129250	34.27862	12.38112	637.8246	378.3489	1016.174	983.8265	49.19
2.479725	1.487835	.2447848	.1219821	.4298261	4.884424	1.714533	79.01970	28.54119	2232.386	1324.221	3556.607	3443.393	49.19
2.792785	1.675671	.2756884	.1373821	.4840907	5.501072	1.930989	100.2313	36.20262	3189.123	1891.745	5080.868	4919.132	49.19
2.967777	1.780666	.2929627	.1459903	.5144231	5.845762	2.051983	113.1855	40.88157	3826.948	2270.093	6097.041	5902.959	49.19
3.196941	1.918165	.3155844	.1572632	.5541455	6.297156	2.210431	131.3402	47.43886	4783.685	2837.617	7621.302	7378.698	49.19
3.333142	1.999885	.3290295	.1639632	.5777541	6.565437	2.304604	142.7697	51.56710	5421.510	3215.966	8637.475	8362.525	49.19
3.518689	2.111213	.3473456	.1730906	.6099161	6.930917	2.432894	159.1073	57.46808	6378.246	3783.489	10161.74	9838.265	49.19
3.632273	2.179364	.3585580	.1786780	.6296042	7.154648	2.511428	169.5451	61.23812	7016.071	4161.838	11177.91	10822.09	49.19
3.790393	2.274236	.3741667	.1864562	.6570122	7.466104	2.620756	184.6276	66.68581	7972.808	4729.361	12702.17	12297.83	49.19
CASE 2 (continued)													
1.135997	.5636122	.1905730	.0941647	.1768337	1.853697	.7361707	13.18050	5.273231	168.7056	101.5132	270.2188	229.7812	45.96
1.431266	.7101069	.2401070	.1186401	.2227965	2.335512	.9275170	20.92274	8.370732	337.4112	203.0264	540.4376	459.5624	45.96
1.803282	.8946786	.3025158	.1494771	.2807060	2.942561	1.168598	33.21278	13.28771	674.8224	406.0528	1080.875	919.1248	45.96
2.737914	1.358386	.4593081	.2269503	.4261944	4.467674	1.774276	76.56270	30.63107	2361.878	1421.185	3783.063	3216.937	45.96
3.083570	1.529879	.5172948	.2556023	.4800006	5.031709	1.998275	97.11475	38.85350	3374.112	2030.264	5404.376	4595.624	45.96
3.276782	1.625739	.5497077	.2716179	.5100767	5.346988	2.123484	109.6662	43.87505	4048.935	2436.317	6485.251	5514.749	45.96
3.529806	1.751274	.5921547	.2925916	.5494635	5.759869	2.287454	127.2563	50.91248	5061.168	3045.396	8106.564	6893.436	45.96
3.680188	1.825885	.6173826	.3050570	.5728726	6.005260	2.384907	138.3305	55.34300	5735.991	3451.449	9187.439	7812.561	45.96
3.885054	1.927527	.6517506	.3220387	.6047628	6.339556	2.517668	154.1601	61.67608	6748.224	4060.528	10808.75	9191.248	45.96
4.010464	1.989747	.6727892	.3324341	.6242846	6.544197	2.598939	164.2733	65.72217	7423.047	4466.581	11889.63	10110.37	45.96
4.185048	2.076365	.7020770	.3469057	.6514610	6.829079	2.712076	178.8869	71.56875	8435.280	5075.660	13510.94	11489.06	45.96
CASE 3 (continued)													
1.295016	.5190666	.2669703	.1304116	.1748202	1.710474	.7519118	12.90722	5.844318	189.2124	112.5070	301.7195	198.2805	39.66
1.631617	.6539829	.3363615	.1643083	.2202596	2.155062	.9473495	20.48894	9.277277	378.4249	225.0140	603.4389	396.5611	39.66
2.055709	.8239669	.4237890	.2070154	.2775097	2.715208	1.193586	32.52417	14.72676	756.8498	450.0281	1206.878	793.1222	39.66
3.121172	1.251024	.6434365	.3143104	.4213415	4.122486	1.812214	74.97530	33.94839	2648.974	1575.098	4224.072	2775.928	39.66
3.515213	1.408964	.7246690	.3539914	.4745349	4.642941	2.041003	95.10124	43.06130	3784.249	2250.140	6034.389	3965.611	39.66
3.735471	1.497247	.7700757	.3761720	.5042686	4.933861	2.168889	107.3924	48.62669	4541.099	2700.168	7241.267	4758.733	39.66
4.023914	1.612861	.8295389	.4052190	.5432069	5.314841	2.336365	124.6179	56.42627	5676.373	3375.210	9051.584	5948.416	39.66
4.195347	1.681574	.8648802	.4224828	.5663495	5.541272	2.435902	135.4624	61.33661	6433.223	3825.239	10258.46	6741.538	39.66
4.428891	1.775183	.9130257	.4460012	.5978766	5.849739	2.571502	150.9638	68.35556	7568.498	4500.281	12068.78	7931.222	39.66
4.571856	1.832486	.9424983	.4603982	.6171761	6.038569	2.654510	160.8674	72.83984	8325.348	4950.309	13275.66	8724.344	39.66
4.770878	1.912258	.9835271	.4804403	.6440430	6.301441	2.770067	175.1780	79.31960	9460.622	5625.351	15085.97	9914.027	39.66
CASE 4 (continued)													
1.524198	.4819936	.3318612	.1600492	.1725979	1.593036	.7592595	12.68793	6.509206	223.0018	125.3065	348.3084	151.6916	30.34
1.920369	.6072739	.4181189	.2016493	.2174597	2.007100	.9566070	20.14084	10.33272	446.0037	250.6131	696.6168	303.3832	30.34
2.419513	.7651171	.5267968	.2540622	.2739820	2.528788	1.205249	31.97159	16.40217	892.0074	501.2262	1393.234	606.7664	30.34
3.673533	1.161673	.7998327	.3857413	.4159854	3.839444	1.829923	73.70149	37.81058	3122.026	1754.292	4876.317	2123.683	30.34
4.137309	1.308332	.9008099	.4344403	.4685027	4.324166	2.060947	93.48549	47.96024	4460.037	2506.131	6966.168	3033.832	30.34
4.396547	1.390310	.9572534	.4616617	.4978584	4.595112	2.190083	105.5679	54.15877	5352.044	3007.357	8359.401	3640.599	30.34
4.736036	1.497666	1.031170	.4973100	.5363017	4.949934	2.359196	122.5006	62.84569	6690.055	3759.196	10449.25	4550.748	30.34
4.937808	1.561472	1.075101	.5184972	.5591501	5.160819	2.459706	133.1609	68.31466	7582.063	4260.422	11842.49	5157.515	30.34
5.212682	1.648395	1.134949	.5473605	.5902764	5.448108	2.596631	148.3990	76.13213	8920.074	5012.262	13932.34	6067.664	30.34
5.380948	1.701605	1.171586	.5650294	.6093306	5.623973	2.680450	158.1343	81.12657	9812.081	5513.488	15325.57	6674.431	30.34
5.615192	1.775680	1.222587	.5896262	.6358560	5.868796	2.797136	172.2017	88.34351	11150.09	6265.327	17415.42	7584.581	30.34
CASE 5 (continued)													
1.860138	.4511496	.3868116	.1841282	.1703567	1.497270	.7606631	12.49695	7.185248	276.8213	138.3208	415.1421	84.85786	16.97
2.343626	.5684129	.4873521	.2319870	.2146360	1.886443	.9583754	19.83767	11.40587	553.6427	276.6416	830.2843	169.7157	16.97
2.952784	.7161554	.6140251	.2922853	.2704244	2.376769	1.207477	31.49034	18.10569	1107.285	553.2833	1660.569	339.4314	16.97
4.483196	1.087335	.9322710	.4437751	.4105839	3.608635	1.833306	72.59210	41.73757	3875.499	1936.491	5811.990	1188.010	16.97
5.049190	1.224608	1.049968	.4998008	.4624193	4.064217	2.064757	92.07831	52.94136	5536.427	2766.416	8302.843	1697.157	16.97
5.365565	1.301341	1.115758	.5311176	.4913938	4.318875	2.194132	103.9788	59.78368	6643.712	3319.700	9963.411	2036.589	16.97
5.779880	1.401827	1.201914	.5721291	.5293379	4.652367	2.363557	120.6567	69.37281	8304.640	4149.624	12454.26	2545.736	16.97
6.026123	1.461550	1.253119	.5965038	.5518896	4.850575	2.464253	131.1565	75.40979	9411.925	4702.908	14114.83	2885.167	16.97
6.361581	1.542910	1.322877	.6297095	.5826118	5.120593	2.601431	146.1652	84.03917	11072.85	5532.833	16605.69	3394.314	16.97
6.566933	1.592715	1.365580	.6500366	.6014185	5.285886	2.685406	155.7540	89.55233	12180.14	6086.116	18266.25	3733.746	16.97
6.852805	1.662049	1.425026	.6783340	.6275995	5.515992	2.802307	169.6097	97.51882	13841.07	6916.041	20757.11	4242.893	16.97

Spreadsheet to Calculate the Parameters of a Cylindrical Buoy with Torospherical End Bells (continued)
27 July 1990

Weight Thin Shell (1/8 pl) lb Wt
MODEL CALCULATION LINE
100.3792
CASE 1 (concluded)
94.43636
149.9084
237.9647
548.5606
695.8130
785.7421
911.7730
991.1175
1104.534
1176.994
1281.699
CASE 2 (concluded)
94.11402
149.3967
237.1525
546.6882
693.4381
783.0602
908.6609
987.7346
1100.764
1172.977
1277.324
CASE 3 (continued)
95.63287
151.8077
240.9797
555.5108
704.6290
795.6975
923.3252
1003.675
1118.529
1191.907
1297.938
CASE 4 (continued)
97.90541
155.4151
246.7062
568.7115
721.3732
814.6058
945.2663
1027.526
1145.109
1220.230
1328.781
CASE 5 (continued)
100.3792
159.3421
252.9398
583.0813
739.6003
835.1887
969.1506
1053.488
1174.042
1251.062
1362.355

Spreadsheet to Calculate the Parameters of a Cylindrical Buoy with Semielliptical End Bells
27 July 1990

assign Gross Displa-cement lb Dg	Buoy Volume cu ft Vb	Buoy Diameter ft Db	assign Bell Height inverse Aspect ratio a	assign Bell Flange to Dia inverse ratio f	assign Working Depth ft d	assign Mat'l Allowable Stress ksi Sa	Buoy Major semi-axis ft W	Buoy Minor semi-axis ft H	** r MUST be less than H Flange Radius ft r	Flange Center Offset Radius ft w	Crown Bulge Height ft h	Crown half Arc rad phi(r)	Crown half Arc deg phi(d)
MODEL CALCULATION LINE													
500	7.776050	2.147285	2	6	2000	24000	1.073643	.5368213	.3578809	.7157617	.1789404	.4899573	28.07249
CASE 6:													
500	7.776050	2.147285	1.2	8	2000	24000	1.073643	.8947021	.2684106	.8052319	.6262915	1.322086	75.74997
1000	15.55210	2.705410	1.2	8	2000	24000	1.352705	1.127254	.3381762	1.014529	.7890778	1.322086	75.74997
2000	31.10420	3.408603	1.2	8	2000	24000	1.704301	1.420251	.4260753	1.278226	.9941758	1.322086	75.74997
7000	108.8647	5.175263	1.2	8	2000	24000	2.587631	2.156359	.6469078	1.940723	1.509452	1.322086	75.74997
10000	155.5210	5.828629	1.2	8	2000	24000	2.914314	2.428595	.7285786	2.185736	1.700017	1.322086	75.74997
12000	186.6252	6.193842	1.2	8	2000	24000	3.096921	2.580768	.7742303	2.322691	1.806537	1.322086	75.74997
15000	233.2815	6.672114	1.2	8	2000	24000	3.336057	2.780048	.8340143	2.502043	1.946033	1.322086	75.74997
17000	264.3857	6.956370	1.2	8	2000	24000	3.478185	2.898488	.8695463	2.608639	2.028941	1.322086	75.74997
20000	311.0420	7.343612	1.2	8	2000	24000	3.671806	3.059838	.9179515	2.753854	2.141887	1.322086	75.74997
22000	342.1462	7.580664	1.2	8	2000	24000	3.790332	3.158610	.9475831	2.842749	2.211027	1.322086	75.74997
25000	388.8025	7.910666	1.2	8	2000	24000	3.955333	3.296111	.9888333	2.966500	2.307278	1.322086	75.74997
CASE 7:													
500	7.776050	2.147285	1.4	8	2000	24000	1.073643	.7668875	.2684106	.8052319	.4984769	1.108615	63.51896
1000	15.55210	2.705410	1.4	8	2000	24000	1.352705	.9662178	.3381762	1.014529	.6280415	1.108615	63.51896
2000	31.10420	3.408603	1.4	8	2000	24000	1.704301	1.217358	.4260753	1.278226	.7912828	1.108615	63.51896
7000	108.8647	5.175263	1.4	8	2000	24000	2.587631	1.848306	.6469078	1.940723	1.201400	1.108615	63.51896
10000	155.5210	5.828629	1.4	8	2000	24000	2.914314	2.081653	.7285786	2.185736	1.353074	1.108615	63.51896
12000	186.6252	6.193842	1.4	8	2000	24000	3.096921	2.212086	.7742303	2.322691	1.437856	1.108615	63.51896
15000	233.2815	6.672114	1.4	8	2000	24000	3.336057	2.382898	.8340143	2.502043	1.548884	1.108615	63.51896
17000	264.3857	6.956370	1.4	8	2000	24000	3.478185	2.484418	.8695463	2.608639	1.614872	1.108615	63.51896
20000	311.0420	7.343612	1.4	8	2000	24000	3.671806	2.622719	.9179515	2.753854	1.704767	1.108615	63.51896
22000	342.1462	7.580664	1.4	8	2000	24000	3.790332	2.707380	.9475831	2.842749	1.759797	1.108615	63.51896
25000	388.8025	7.910666	1.4	8	2000	24000	3.955333	2.825238	.9888333	2.966500	1.836405	1.108615	63.51896
CASE 8:													
500	7.776050	2.147285	1.6	8	2000	24000	1.073643	.6710266	.2684106	.8052319	.4026160	.9272952	53.13010
1000	15.55210	2.705410	1.6	8	2000	24000	1.352705	.8454405	.3381762	1.014529	.5072643	.9272952	53.13010
2000	31.10420	3.408603	1.6	8	2000	24000	1.704301	1.065188	.4260753	1.278226	.6391130	.9272952	53.13010
7000	108.8647	5.175263	1.6	8	2000	24000	2.587631	1.617270	.6469078	1.940723	.9703617	.9272952	53.13010
10000	155.5210	5.828629	1.6	8	2000	24000	2.914314	1.821446	.7285786	2.185736	1.092868	.9272952	53.13010
12000	186.6252	6.193842	1.6	8	2000	24000	3.096921	1.935576	.7742303	2.322691	1.161345	.9272952	53.13010
15000	233.2815	6.672114	1.6	8	2000	24000	3.336057	2.085036	.8340143	2.502043	1.251021	.9272952	53.13010
17000	264.3857	6.956370	1.6	8	2000	24000	3.478185	2.173866	.8695463	2.608639	1.304319	.9272952	53.13010
20000	311.0420	7.343612	1.6	8	2000	24000	3.671806	2.294879	.9179515	2.753854	1.376927	.9272952	53.13010
22000	342.1462	7.580664	1.6	8	2000	24000	3.790332	2.368958	.9475831	2.842749	1.421375	.9272952	53.13010
25000	388.8025	7.910666	1.6	8	2000	24000	3.955333	2.472083	.9888333	2.966500	1.483250	.9272952	53.13010
CASE 9:													
500	7.776050	2.147285	1.8	8	2000	24000	1.073643	.5964681	.2684106	.8052319	.3280575	.7737514	44.33269
1000	15.55210	2.705410	1.8	8	2000	24000	1.352705	.7515027	.3381762	1.014529	.4133265	.7737514	44.33269
2000	31.10420	3.408603	1.8	8	2000	24000	1.704301	.9468341	.4260753	1.278226	.5207587	.7737514	44.33269
7000	108.8647	5.175263	1.8	8	2000	24000	2.587631	1.437573	.6469078	1.940723	.7906651	.7737514	44.33269
10000	155.5210	5.828629	1.8	8	2000	24000	2.914314	1.619063	.7285786	2.185736	.8904849	.7737514	44.33269
12000	186.6252	6.193842	1.8	8	2000	24000	3.096921	1.720512	.7742303	2.322691	.9462814	.7737514	44.33269
15000	233.2815	6.672114	1.8	8	2000	24000	3.336057	1.853365	.8340143	2.502043	1.019351	.7737514	44.33269
17000	264.3857	6.956370	1.8	8	2000	24000	3.478185	1.932325	.8695463	2.608639	1.062779	.7737514	44.33269
20000	311.0420	7.343612	1.8	8	2000	24000	3.671806	2.039892	.9179515	2.753854	1.121941	.7737514	44.33269
22000	342.1462	7.580664	1.8	8	2000	24000	3.790332	2.105740	.9475831	2.842749	1.158157	.7737514	44.33269
25000	388.8025	7.910666	1.8	8	2000	24000	3.955333	2.197407	.9888333	2.966500	1.208574	.7737514	44.33269
CASE 10:													
500	7.776050	2.147285	2	8	2000	24000	1.073643	.5368213	.2684106	.8052319	.2684106	.6435011	36.86990
1000	15.55210	2.705410	2	8	2000	24000	1.352705	.6763524	.3381762	1.014529	.3381762	.6435011	36.86990
2000	31.10420	3.408603	2	8	2000	24000	1.704301	.8521507	.4260753	1.278226	.4260753	.6435011	36.86990
7000	108.8647	5.175263	2	8	2000	24000	2.587631	1.293816	.6469078	1.940723	.6469078	.6435011	36.86990
10000	155.5210	5.828629	2	8	2000	24000	2.914314	1.457157	.7285786	2.185736	.7285786	.6435011	36.86990
12000	186.6252	6.193842	2	8	2000	24000	3.096921	1.548461	.7742303	2.322691	.7742303	.6435011	36.86990
15000	233.2815	6.672114	2	8	2000	24000	3.336057	1.668029	.8340143	2.502043	.8340143	.6435011	36.86990
17000	264.3857	6.956370	2	8	2000	24000	3.478185	1.739093	.8695463	2.608639	.8695463	.6435011	36.86990
20000	311.0420	7.343612	2	8	2000	24000	3.671806	1.835903	.9179515	2.753854	.9179515	.6435011	36.86990
22000	342.1462	7.580664	2	8	2000	24000	3.790332	1.895166	.9475831	2.842749	.9475831	.6435011	36.86990
25000	388.8025	7.910666	2	8	2000	24000	3.955333	1.977667	.9888333	2.966500	.9888333	.6435011	36.86990

Cylindrical Buoy with Torospherical End Bell

Flange Arc Angle rad theta(r)	Flange Arc Angle deg theta(d)	Crown Radius ft R	Crown Height ft C	Crown Volume cu ft Vc	Flange Volume cu ft Vf	Volume End Bells cu ft Ve	Volume Cylindrical Section cu ft Vc	Knuckle Stress Correction factor M	Thickness End Bell in te	Thickness Cylinder Wall in tc	Length Cylinder Wall ft Lc	ft ll	ft cl
MODEL CALCULATION LINE (continued)													
1.080839	61.92751	1.878874	.2210441	.2770966	1.682331	3.918856	3.857194	1.322822	.5429194	.4718300	1.065129	.9205683	.9113880
CASE 6 (continued)													
.2487100	14.25003	1.099205	.8286318	1.775294	.7972415	5.145071	2.630979	1.255917	.3019294	.4718300	.7265209	1.453245	1.349694
.2487100	14.25003	1.384912	1.044011	3.550587	1.594483	10.29014	5.261958	1.255917	.3804072	.5944686	.9153590	1.830973	1.700508
.2487100	14.25003	1.744880	1.315371	7.101175	3.188966	20.58028	10.52392	1.255917	.4792831	.7489835	1.153280	2.306882	2.142505
.2487100	14.25003	2.649242	1.997121	24.85411	11.16138	72.03099	36.83371	1.255917	.7276928	1.137178	1.751019	3.502526	3.252954
.2487100	14.25003	2.983703	2.249253	35.50587	15.94483	102.9014	52.61958	1.255917	.8195625	1.280744	1.972081	3.944713	3.663633
.2487100	14.25003	3.170657	2.390188	42.60705	19.13380	123.4817	63.14350	1.255917	.8709151	1.360993	2.095649	4.191883	3.893191
.2487100	14.25003	3.415487	2.574752	53.25881	23.91725	154.3521	78.92938	1.255917	.9381649	1.466086	2.257469	4.515569	4.193812
.2487100	14.25003	3.560999	2.684445	60.35999	27.10621	174.9324	89.45329	1.255917	.9781341	1.528546	2.353646	4.707948	4.372484
.2487100	14.25003	3.759230	2.833881	71.01175	31.88966	205.8028	105.2392	1.255917	1.032584	1.613636	2.484666	4.970026	4.615888
.2487100	14.25003	3.880578	2.925359	78.11292	35.07863	226.3831	115.7631	1.255917	1.065916	1.665724	2.564872	5.130459	4.764889
.2487100	14.25003	4.049508	3.052706	88.76469	39.86208	257.2535	131.5490	1.255917	1.112317	1.738237	2.676526	5.353799	4.972314
CASE 7 (continued)													
.4621813	26.48104	1.168029	.6472028	1.253147	1.236545	4.979384	2.796666	1.271515	.3247260	.4718300	.7722738	1.294894	1.229595
.4621813	26.48104	1.471624	.8154244	2.506293	2.473090	9.958767	5.593332	1.271515	.4091291	.5944686	.9730040	1.631464	1.549192
.4621813	26.48104	1.854130	1.027370	5.012587	4.946181	19.91753	11.18666	1.271515	.5154704	.7489835	1.225908	2.055516	1.951860
.4621813	26.48104	2.815115	1.559851	17.54405	17.31163	69.71137	39.15333	1.271515	.7826359	1.137178	1.861290	3.120879	2.963498
.4621813	26.48104	3.170518	1.756779	25.06293	24.73090	99.58767	55.93332	1.271515	.8814420	1.280744	2.096274	3.514884	3.337633
.4621813	26.48104	3.369178	1.866856	30.07552	29.67708	119.5052	67.11999	1.271515	.9366719	1.360993	2.227623	3.735121	3.546765
.4621813	26.48104	3.629337	2.011010	37.59440	37.09635	149.3815	83.89998	1.271515	1.008999	1.466086	2.399634	4.023537	3.820636
.4621813	26.48104	3.783960	2.096686	42.60699	42.04253	169.2990	95.08665	1.271515	1.051986	1.528546	2.501867	4.194954	3.983409
.4621813	26.48104	3.994602	2.213402	50.12587	49.46181	199.1753	111.8666	1.271515	1.110547	1.613636	2.641139	4.428476	4.205154
.4621813	26.48104	4.123548	2.284851	55.13845	54.40799	219.0929	123.0533	1.271515	1.146396	1.665724	2.726396	4.571427	4.340897
.4621813	26.48104	4.303055	2.384316	62.65733	61.82726	248.9692	139.8333	1.271515	1.196301	1.738237	2.845081	4.770431	4.529865
CASE 8 (continued)													
.6435011	36.86990	1.274951	.5099802	.9028217	1.453635	4.712914	3.063136	1.294862	.3608064	.4718300	.8458570	1.182256	1.140350
.6435011	36.86990	1.606337	.6425348	1.805643	2.907271	9.425828	6.126272	1.294862	.4545876	.5944686	1.065713	1.489549	1.436752
.6435011	36.86990	2.023858	.8095431	3.611287	5.814541	18.85166	12.25254	1.294862	.5727445	.7489835	1.342714	1.876714	1.810193
.6435011	36.86990	3.072812	1.229125	12.63950	20.35089	65.98079	42.88390	1.294862	.8695948	1.137178	2.038636	2.849404	2.748407
.6435011	36.86990	3.460748	1.384299	18.05643	29.07271	94.25828	61.26272	1.294862	.9793793	1.280744	2.296009	3.209135	3.095387
.6435011	36.86990	3.677594	1.471038	21.66772	34.88725	113.1099	73.51526	1.294862	1.040746	1.360993	2.439874	3.410215	3.289340
.6435011	36.86990	3.961568	1.584627	27.08465	43.60906	141.3874	91.89408	1.294862	1.121109	1.466086	2.628274	3.673543	3.543334
.6435011	36.86990	4.130345	1.652138	30.69594	49.42360	160.2391	104.1466	1.294862	1.168873	1.528546	2.740248	3.830049	3.694293
.6435011	36.86990	4.360270	1.744108	36.11287	58.14541	188.5166	122.5254	1.294862	1.233941	1.613636	2.892790	4.043257	3.899944
.6435011	36.86990	4.501020	1.800408	39.72415	63.95995	207.3682	134.7780	1.294862	1.273772	1.665724	2.986170	4.173774	4.025834
.6435011	36.86990	4.696958	1.878783	45.14108	72.68177	235.6457	153.1568	1.294862	1.329222	1.738237	3.116164	4.355467	4.201087
CASE 9 (continued)													
.7970449	45.66731	1.420679	.4044755	.6608849	1.537634	4.397038	3.379012	1.325159	.4112270	.4718300	.9330832	1.099252	1.072035
.7970449	45.66731	1.789943	.5096072	1.321770	3.075268	8.794076	6.758023	1.325159	.5181135	.5944686	1.175611	1.384971	1.350680
.7970449	45.66731	2.255187	.6420649	2.643540	6.150536	17.58815	13.51605	1.325159	.6527822	.7489835	1.481177	1.744954	1.701750
.7970449	45.66731	3.424037	.9748436	9.252389	21.52688	61.55853	47.30616	1.325159	.9911156	1.137178	2.248863	2.649354	2.583757
.7970449	45.66731	3.856315	1.097916	13.21770	30.75268	87.94076	67.58023	1.325159	1.116242	1.280744	2.532778	2.983829	2.909951
.7970449	45.66731	4.097946	1.166709	15.86124	36.90322	105.5289	81.09628	1.325159	1.186184	1.360993	2.691478	3.170792	3.092285
.7970449	45.66731	4.414379	1.256800	19.82655	46.12902	131.9111	101.3704	1.325159	1.277778	1.466086	2.899307	3.415632	3.331063
.7970449	45.66731	4.602447	1.310344	22.47009	52.27956	149.4993	114.8864	1.325159	1.332216	1.528546	3.022827	3.561150	3.472978
.7970449	45.66731	4.858652	1.383287	26.43540	61.50536	175.8815	135.1605	1.325159	1.406377	1.613636	3.191100	3.759389	3.666309
.7970449	45.66731	5.015490	1.427940	29.07894	67.65590	193.4697	148.6765	1.325159	1.451775	1.665724	3.294109	3.880743	3.784658
.7970449	45.66731	5.233825	1.490101	33.04425	76.88170	219.8519	168.9506	1.325159	1.514973	1.738237	3.437508	4.049679	3.949411
CASE 10 (continued)													
.9272952	53.13010	1.610464	.3220928	.4898911	1.544842	4.069466	3.706584	1.362372	.4789283	.4718300	1.023539	1.036335	1.018547
.9272952	53.13010	2.029057	.4058115	.9797823	3.089684	8.138932	7.413167	1.362372	.6034118	.5944686	1.289579	1.305701	1.283289
.9272952	53.13010	2.556452	.5112904	1.959565	6.179368	16.27786	14.82633	1.362372	.7602513	.7489835	1.624767	1.645080	1.616842
.9272952	53.13010	3.881447	.7762894	6.858476	21.62779	56.97252	51.89217	1.362372	1.154285	1.137178	2.466875	2.497715	2.454843
.9272952	53.13010	4.371471	.8742943	9.797823	30.89684	81.38932	74.13167	1.362372	1.300011	1.280744	2.778313	2.813047	2.764761
.9272952	53.13010	4.645382	.9290763	11.75739	37.07621	97.66719	88.95801	1.362372	1.381468	1.360993	2.952398	2.989308	2.937997
.9272952	53.13010	5.004086	1.000817	14.69673	46.34526	122.0840	111.1975	1.362372	1.488142	1.466086	3.180374	3.220135	3.164862
.9272952	53.13010	5.217278	1.043456	16.65630	52.52462	138.3618	126.0238	1.362372	1.551542	1.528546	3.315870	3.357324	3.299696
.9272952	53.13010	5.507709	1.101542	19.59565	61.79368	162.7786	148.2633	1.362372	1.637912	1.613636	3.500455	3.544217	3.483381
.9272952	53.13010	5.685498	1.137100	21.55521	67.97304	179.0565	163.0897	1.362372	1.690784	1.665724	3.613450	3.658625	3.595825
.9272952	53.13010	5.933000	1.186600	24.49456	77.24209	203.4733	185.3292	1.362372	1.764387	1.738237	3.770751	3.817892	3.752358

Cylindrical Buoy with Torospherical End Bell

ft d1	ft s1	ft 12	ft c2	ft d2	ft s2	Bell Profile CG Radius ft X	End Bells Surface Area sq ft Ase	Cylinder Surface Area sq ft Asc	Weight End Bells lb We	Weight Cylinder Wall lb Wc	Weight Complete Buoy lb Wb	Net Buoyancy lb B	Effic-iency % E
MODEL CALCULATION LINE (continued)													
1.860138	.4511495	.3868116	.1841282	.1703567	1.497270	.7606631	12.49695	7.185248	276.8213	138.3208	415.1421	84.85786	16.97
CASE 6 (continued)													
1.020882	.6267608	.0667564	.0332922	.1338597	2.144503	.6934180	13.24490	4.901034	163.1603	94.34816	257.5084	242.4916	48.50
1.286230	.7896691	.0841078	.0419456	.1686526	2.701905	.8736519	21.02497	7.779906	326.3205	188.6963	515.0169	484.9831	48.50
1.620549	.9949207	.1059692	.0528481	.2124890	3.404187	1.100732	33.37507	12.34983	652.6411	377.3926	1030.034	969.9663	48.50
2.460470	1.510583	.1608924	.0802390	.3226209	5.168558	1.671236	76.93681	28.46905	2284.244	1320.874	3605.118	3394.882	48.50
2.771099	1.701290	.1812048	.0903690	.3633511	5.821077	1.882226	97.58929	36.11113	3263.205	1886.963	5150.169	4849.831	48.50
2.944732	1.807891	.1925588	.0960314	.3861182	6.185818	2.000164	110.2020	40.77824	3915.846	2264.356	6180.202	5819.798	48.50
3.172117	1.947491	.2074277	.1034467	.4159332	6.663470	2.154611	127.8781	47.31896	4894.808	2830.445	7725.253	7274.747	48.50
3.307260	2.030462	.2162648	.1078539	.4336534	6.947358	2.246405	139.0064	51.43676	5547.449	3207.838	8755.286	8244.714	48.50
3.491366	2.143492	.2283037	.1138579	.4577937	7.334098	2.371456	154.9133	57.32284	6526.411	3773.926	10300.34	9699.663	48.50
3.604068	2.212684	.2356734	.1175332	.4725713	7.570843	2.448007	165.0760	61.08334	7179.052	4151.319	11330.37	10669.63	48.50
3.760960	2.309006	.2459327	.1226497	.4931433	7.900417	2.554574	179.7610	66.51726	8158.013	4717.408	12875.42	12124.58	48.50
CASE 7 (continued)													
1.109127	.5837940	.1240544	.0614766	.1330140	2.002140	.7077958	12.62073	5.209678	167.2098	100.2898	267.4996	232.5004	46.50
1.397412	.7355344	.1562987	.0774557	.1675872	2.522539	.8917668	20.03416	8.269849	334.4196	200.5795	534.9991	465.0009	46.50
1.760629	.9267152	.1969241	.0975880	.2111466	3.178200	1.123556	31.80225	13.12757	668.8392	401.1591	1069.998	930.0017	46.50
2.673153	1.407027	.2989887	.1481673	.3205827	4.825443	1.705888	73.31112	30.26190	2340.937	1404.057	3744.994	3255.006	46.50
3.010633	1.584661	.3367354	.1668732	.3610556	5.434645	1.921253	92.99033	38.38524	3344.196	2005.795	5349.991	4650.009	46.50
3.199275	1.683953	.3578348	.1773292	.3836788	5.775172	2.041636	105.0087	43.34627	4013.035	2406.955	6419.990	5580.010	46.50
3.446315	1.813984	.3854658	.1910221	.4133055	6.221116	2.199286	121.8518	50.29889	5016.294	3008.693	8024.987	6975.013	46.50
3.593140	1.891266	.4018881	.1991603	.4309138	6.486158	2.292984	132.4556	54.67601	5685.133	3409.852	9094.985	7905.015	46.50
3.793160	1.996547	.4242600	.2102470	.4549015	6.847224	2.420627	147.6130	60.93277	6688.392	4011.591	10699.98	9300.017	46.50
3.915604	2.060996	.4379552	.2170338	.4695858	7.068253	2.498766	157.2967	64.93009	7357.231	4412.750	11769.98	10230.02	46.50
4.086058	2.150716	.4570203	.2264817	.4900278	7.375948	2.607542	171.2897	70.70621	8360.490	5014.489	13374.98	11625.02	46.50
CASE 8 (continued)													
1.229760	.5499653	.1727225	.0848789	.1319017	1.887063	.7204087	12.26651	5.706063	180.5741	109.8455	290.4196	209.5804	41.92
1.549400	.6929129	.2176168	.1069407	.1661857	2.377551	.9076580	19.47187	9.057810	361.1482	219.6910	580.8392	419.1608	41.92
1.952122	.8730155	.2741800	.1347369	.2093809	2.995526	1.143577	30.90967	14.37838	722.2964	439.3820	1161.678	838.3215	41.92
2.963896	1.325495	.4162859	.2045702	.3179019	4.548091	1.736287	71.25353	33.14530	2528.038	1537.837	4065.875	2934.125	41.92
3.338082	1.492836	.4688411	.2303968	.3580363	5.122278	1.955490	90.38043	42.04263	3611.482	2196.910	5808.392	4191.608	41.92
3.547241	1.586375	.4982180	.2448331	.3804704	5.443233	2.078018	102.0615	47.47635	4333.779	2636.292	6970.071	5029.929	41.92
3.821150	1.708870	.5366891	.2637385	.4098493	5.863545	2.238477	118.4319	55.09143	5417.223	3295.365	8712.588	6287.412	41.92
3.983945	1.781674	.5595540	.2749747	.4273103	6.113353	2.333844	128.7381	59.88561	6139.520	3734.747	9874.267	7125.733	41.92
4.205720	1.880855	.5907028	.2902817	.4510975	6.453666	2.463763	143.4700	66.73851	7222.964	4393.820	11616.78	8383.215	41.92
4.341481	1.941569	.6097708	.2996521	.4656590	6.661991	2.543293	152.8819	71.11671	7945.261	4833.202	12778.46	9221.537	41.92
4.530474	2.026090	.6363153	.3126965	.4859301	6.952001	2.654008	166.4822	77.44318	9028.706	5492.275	14520.98	10479.02	41.92
CASE 9 (continued)													
1.385503	.5227461	.2139353	.1041586	.1306810	1.793257	.7297289	12.04199	6.294482	202.0412	121.1730	323.2142	176.7858	35.36
1.745625	.6586188	.2695416	.1312316	.1646478	2.259363	.9194009	19.11546	9.991867	404.0824	242.3459	646.4283	353.5717	35.36
2.199349	.8298077	.3396012	.1653415	.2074432	2.846619	1.158372	30.34390	15.86110	808.1648	484.6919	1292.857	707.1434	35.36
3.339260	1.259892	.5156146	.2510371	.3149598	4.322006	1.758751	69.94932	36.56330	2828.577	1696.421	4524.998	2475.002	35.36
3.760835	1.418951	.5807098	.2827300	.3547228	4.867650	1.980789	88.72612	46.37814	4040.824	2423.459	6464.283	3535.717	35.36
3.996483	1.507861	.6170963	.3004455	.3769492	5.172650	2.104903	100.1934	52.37220	4848.989	2908.151	7757.140	4242.860	35.36
4.305081	1.624294	.6647468	.3236451	.4060563	5.572068	2.267437	116.2641	60.77255	6061.236	3635.189	9696.425	5303.575	35.36
4.488493	1.693494	.6930674	.3374335	.4233557	5.809458	2.364038	126.3817	66.06112	6869.400	4119.881	10989.28	6010.719	35.36
4.738355	1.787766	.7316485	.3562175	.4469228	6.132854	2.495638	140.8439	73.62070	8081.648	4846.919	12928.57	7071.434	35.36
4.891309	1.845476	.7552662	.3677162	.4613495	6.330824	2.576197	150.0836	78.45039	8889.812	5331.610	14221.42	7778.577	35.36
5.104238	1.925813	.7881445	.3837237	.4814329	6.606417	2.688344	163.4349	85.42926	10102.06	6058.648	16160.71	8839.292	35.36
CASE 10 (continued)													
1.582821	.5005318	.2488959	.1200369	.1294484	1.716248	.7359655	11.88635	6.904688	232.2626	132.9199	365.1824	134.8176	26.96
1.994229	.6306306	.3135892	.1512370	.1630948	2.162337	.9272584	18.86841	10.96051	464.5251	265.8397	730.3648	269.6352	26.96
2.512571	.7945447	.3950976	.1905467	.2054865	2.724374	1.168272	29.95173	17.39872	929.0503	531.6794	1460.730	539.2703	26.96
3.814823	1.206353	.5998745	.2893060	.3119891	4.136401	1.773782	69.04527	40.10786	3251.676	1860.878	5112.554	1887.446	26.96
4.296436	1.358652	.6756074	.3258302	.3513770	4.658613	1.997718	87.57939	50.87418	4645.251	2658.397	7303.648	2696.352	26.96
4.565644	1.443784	.7179400	.3462463	.3733938	4.950515	2.122892	98.89843	57.44932	5574.302	3190.076	8764.378	3235.622	26.96
4.918191	1.555269	.7733774	.3729825	.4022263	5.332781	2.286816	114.7615	66.66403	6967.877	3987.596	10955.47	4044.527	26.96
5.127724	1.621529	.8063261	.3888729	.4193626	5.559977	2.384243	124.7483	72.46529	7896.927	4519.275	12416.20	4583.798	26.96
5.413170	1.711795	.8512120	.4105204	.4427073	5.869485	2.516967	139.0236	80.75773	9290.503	5316.794	14607.30	5392.703	26.96
5.587908	1.767052	.8786892	.4237720	.4569980	6.058953	2.598215	148.1439	86.05561	10219.55	5848.473	16068.03	5931.973	26.96
5.831161	1.843975	.9169404	.4422197	.4768920	6.322711	2.711320	161.3226	93.71104	11613.13	6645.993	18259.12	6740.879	26.96

Cylindrical Buoy with Torospherical End Bells

```
          Weight
           Thin
          Shell
         (1/8 pl)

            lb
            Wt
------------------
MODEL CALCULATION LINE  (continued)

          100.3792

CASE 6 (continued)
          92.54428
          146.9049
          233.1970
          537.5699
          681.8721
          769.9995
          893.5052
          971.2601
          1082.404
          1153.413
          1256.019

CASE 7 (continued)
          90.93508
          144.3504
          229.1420
          528.2224
          670.0154
          756.6104
          877.9686
          954.3714
          1063.583
          1133.357
          1234.179

CASE 8 (continued)
          91.66013
          145.5014
          230.9690
          532.4340
          675.3576
          762.6430
          884.9688
          961.9808
          1072.063
          1142.393
          1244.019

CASE 9 (continued)
          93.51599
          148.4474
          235.6455
          543.2143
          689.0317
          778.0844
          902.8869
          981.4582
          1093.770
          1165.523
          1269.207

CASE 10 (continued)
          95.83431
          152.1275
          241.4873
          556.6809
          706.1132
          797.3736
          925.2700
          1005.789
          1120.885
          1194.417
          1300.672
```

7 August 1990

Expressions for the Calculation of Parameters used in Cylindrical Buoy with Dished and Flanged End Bells

SuperCalc ver. 2.1

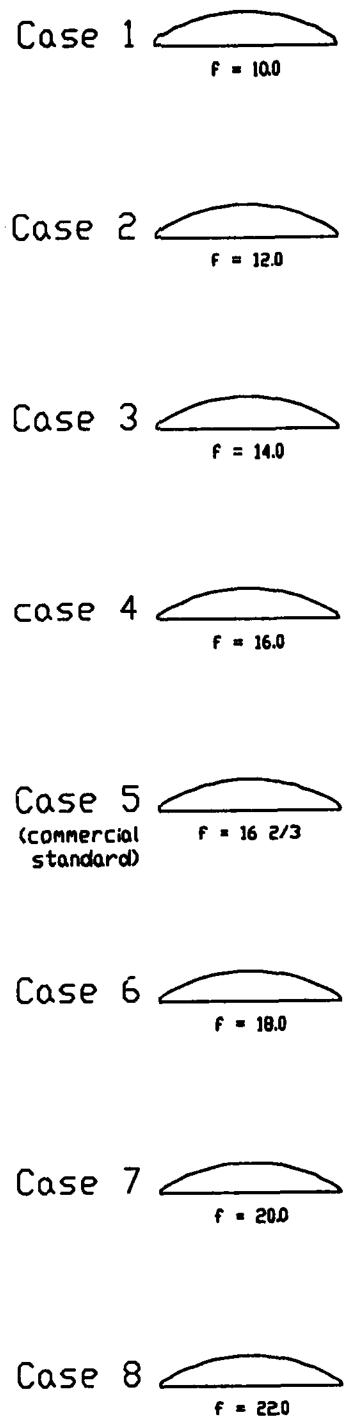
COL	SYMB	EXPRESSION	DESCRIPTION	UNITS	EQUATION
A	D_g	= 500	Buoy Gross Displacement	lb	assigned
B	d_w	= 2000	Buoy Volume	cu ft	assigned
C	S_a	= 24000	Material Allowable Stress	psi	assigned
D	V_b	= A13/64.3	Buoy Total Volume	cu ft	D_g / 64.3
E	D_b	= (4*D13/PI)^(1/3)	Buoy Diameter	ft	$(4\ V_b / \pi)^{1/3}$
F	R_c	= E13	Bell Crown Radius	ft	assigned
G	f	= 10	Flange : Diameter Ratio	-	assigned
H	r	= E13/G13	Flange Radius	ft	D_b / f
I	w	= (E13/2)-H13	Flange Center Offset	ft	$(D_b/2) - r$
J	L	= E13-H13	Flange Center Radius	ft	$D_b - r$
K	$\phi(r)$	= ASIN(I13/J13)	Crown Arc Half Angle	radians	$\mathrm{asin}(w / L)$
L	$\phi(d)$	= K13*180/PI	" " " "	degrees	$180\ \phi(r) / \pi$
M	$\theta(r)$	= PI/2-K13	Flange Arc Angle	radians	$(\pi / 2) - \phi(r)$
N	$\theta(d)$	= 90-L13	" " "	degrees	$90 - \phi(d)$
O	h	= J13*COS(K13)	Crown Center Offset	ft	$L \cos\phi(r)$
P	C	= F13-O13	Bell Height	ft	$R_c - h$
Q	V_c	= PI/3*P13^2*(3*F13-P13)	Crown Volume	cu ft	$\pi/3\ C^2\ (3\ R_c - C)$
R	V_f	= PI*(E13^2/4*H13*SIN(M13)-((H13*SIN(M13))^3)/3)	Flange Disk Volume	cu ft	$\pi(D^2/4\ r \sin\theta - ((r \sin\theta)^3) / 3)$
S	V_e	= Q13+R13	End Bell Volume	cu ft	$V_c + V_f$
T	V_{cl}	= D13-2*S13	Volume Cylinder Section	cu ft	$V_b - 2\ V_e$
U	L_c	= 4*T13/PI/E13^2	Length Cyinder Section	ft	$(4\ V_{cl} / (\pi\ D_b^2)$
V	L_b	= U13+2*P13	Total Buoy Length	ft	$L_c + 2\ C$
W	M	= (3+(F13/H13)^(1/2))/4	Knuckle Stress Factor	-	$(3 + (R / r)^{1/2}) / 4$
X	P	= .446*B13	Working Pressure	psi	$.446\ d_w$
Y	t_e	= 12*X13*E13/2*W13/(2*C13+(X13*(W13-.2)))	End Bell Thickness	in	$12\ P\ R\ M / (2\ S_a + P(M-0.2))$
Z	t_c	= 12*X13*E13/2/(C13+(.4*X13))	Cylinder Wall Thickness	in	$12\ P\ R / S_a + (0.4\ P)$
AA	l_1	= F13*K13	Surface Area Parameters	ft	$R\ \phi(R)$
AB	c_1	= 2*F13*SIN(K13/2)	" " "	ft	$2\ R \sin(\phi / 2)$
AC	d_1	= F13*AB13/AA13	" " "	ft	$R\ c_1 / l_1$
AD	s_1	= AC13*SIN(K13/2)	" " "	ft	$d_1 \sin(\phi / 2)$
AE	l_2	= H13*M13	" " "	ft	$2\ \pi\ r\ \theta(d) / 360$
AF	c_2	= 2*H13*SIN(M13/2)	" " "	ft	$2\ r \sin(\theta / 2)$
AG	d_2	= H13*AF13/AE13	" " "	ft	$r\ c_2 / l_2$
AH	s_2	= AG13*COS(M13/2)+I13	" " "	ft	$d_2 \cos(\theta / 2) + w$

7 August 1990

Expressions for the Calculation of Parameters used in Cylindrical Buoy with Dished and Flanged End Bells (continued)

COL	SYMB	EXPRESSION	DESCRIPTION	UNITS	EQUATION
AI	X	= (AA13*AD13+(AE13*AH13))/(AA13+AE13)	End Bell Profile CG	sq ft	$(l_1 s_1) + (l_2 s_2) / (l^1 + l_2)$
AJ	A_{se}	= 4*PI*AI13*(AA13+AE13)	End Bell Surface Area	sq ft	$4 \pi X (l^1 + l_2)$
AK	A_{sc}	= PI*E13*U13	Cylinder Surface Area	sq ft	$\pi D_b L_c$
AL	A_{fe}	= PI/180*L13*F13^2-((F13-P12)*(E13/2-H13))+PI*H13^2*N13/360	End Bell Frontal Area	sq ft	$\pi \phi R^2/180 - (R-H)(W-r) + \pi r^2 \theta / 360$
AM	A_{fc}	= E13*U13	Cylinder Frontal Area	sq ft	D_b Lc
AN	A_f	= 2*AL13+AM13	Buoy Frontal Area	sq ft	$A_{fe} + A_{fc}$
AO	W_e	= 40.8*AJ13*Y13	Weight of End Bells	lb	$40.8 A_{se} t_e$
AP	W_c	= AK13*Z13*40.8	Weight Cylinder Sec.	lb	$40.8 A_{sc} t_c$
AQ	W_b	= AO13+AP13	Buoy Weight	lb	$W_e + W_c$
AR	B	= A13-AQ13	Net Buoyancy	lb	$D_s - B$
AS	E	= 100-(100*(A13-AR13)/A13)	Efficiency	%	$100 (100 -(D_s - B) / D_s)$

Dishead and Flanged (Variation of Torospherical Shape) Profiles Corresponding with the Calculated Cases



An AutoLisp Routine Created to Enable Autocad to Construct the Dished and Flanged End Bell Outlines Shown on the Previous Page Is Reproduced Below.

```
(defun c:df ()
; input data values
(setq   p1 (getpoint "\nPick a basepoint for the drawn shape: ")
    D 2.147285 ;(getreal "\nBuoy Diameter - 'D': ")
    F (getreal "\nFlange Ratio - 'f': ")
    P (getreal "\nCrown half angle - 'P': ")
); end setq

; calculate derived values
(setq       E (/ D 2)
    S (/ E F)
    W (- E S)
    L (- D S)
    I (* L (cos P))
    Theta (- (/ PI 2) P)
    x (* S (cos theta))
    y (* S (sin theta))
);end setq

; calculate construction points
(setq  p1x (car p1)
    p1y (cadr p1)
    p2 (list (+ p1x E) p1y)
    p3 (list p1x (+ p1y (- D I)))
    p4 (list p1x (- p1y I))
    p5 (list (+ p1x W) p1y)
    p6 (list (+ p1x W x) (+ p1y y))
);end setq

; construct figure
(command "line" p1 p2 ""
     "arc" p2 "c" p5 p6 \r)
(command "arc" p6 "c" p4 p3 \r)
(command "mirror" "w" p3 p2 "" p1 p3 "n" \r
) ; end of drawing sequence

; install labels
(command "dtext" "c" (list p1x (- p1y 0.3)) 0.125 0 \r)
(command "dtext" "r" (list (- p1x 0.25 E) p1y) 0.25 0 \r
);end text command
);end defun
```

7 August 1990

Spreadsheet to Compute Parameters for Cylindrical Buoys with Dished and Flanged End Bells
Crown Radius and Flange:Diameter Ratio Are Assigned.

Buoy Gross Displace- lb Dg	Buoy Working Depth ft d	Buoy Material Allowable Stress Sa	Buoy Volume cu ft Vb	Buoy Diam- eter ft Db	Bell Crown Radius ft Rc	Flange : Diameter ratio f	Flange Radius ft r	Flange Center Offset ft w	Flange Center Radius ft L	Crown Half Angle radians phi(r)	" " " degrees phi(d)	Flange Arc Angle radians theta(r)	" " " degrees theta(d)
CASE 1: FLANGE : DIAMETER RATIO = 10													
500	2000	24000	7.776050	2.147285	2.147285		10	.2147285	.8589141	1.932557	.4605540	26.38780	1.110242	63.61220
1000	2000	24000	15.55210	2.705410	2.705410		10	.2705410	1.082164	2.434869	.4605540	26.38780	1.110242	63.61220
2000	2000	24000	31.10420	3.408603	3.408603		10	.3408603	1.363441	3.067742	.4605540	26.38780	1.110242	63.61220
5000	2000	24000	77.76050	4.626186	4.626186		10	.4626186	1.850474	4.163567	.4605540	26.38780	1.110242	63.61220
7000	2000	24000	108.8647	5.175263	5.175263		10	.5175263	2.070105	4.657736	.4605540	26.38780	1.110242	63.61220
10000	2000	24000	155.5210	5.828629	5.828629		10	.5828629	2.331451	5.245766	.4605540	26.38780	1.110242	63.61220
12000	2000	24000	186.6252	6.193842	6.193842		10	.6193842	2.477537	5.574458	.4605540	26.38780	1.110242	63.61220
15000	2000	24000	233.2815	6.672114	6.672114		10	.6672114	2.668846	6.004903	.4605540	26.38780	1.110242	63.61220
17000	2000	24000	264.3857	6.956370	6.956370		10	.6956370	2.782548	6.260733	.4605540	26.38780	1.110242	63.61220
20000	2000	24000	311.0420	7.343612	7.343612		10	.7343612	2.937445	6.609251	.4605540	26.38780	1.110242	63.61220
22000	2000	24000	342.1462	7.580664	7.580664		10	.7580664	3.032266	6.822598	.4605540	26.38780	1.110242	63.61220
25000	2000	24000	388.8025	7.910666	7.910666		10	.7910666	3.164266	7.119599	.4605540	26.38780	1.110242	63.61220
CASE 2: FLANGE : DIAMETER RATIO = 12													
500	2000	24000	7.776050	2.147285	2.147285	12	.1789404	.8947021	1.968345	.4718618	27.03569	1.098934	62.96431
1000	2000	24000	15.55210	2.705410	2.705410	12	.2254508	1.127254	2.479959	.4718618	27.03569	1.098934	62.96431
2000	2000	24000	31.10420	3.408603	3.408603	12	.2840502	1.420251	3.124552	.4718618	27.03569	1.098934	62.96431
5000	2000	24000	77.76050	4.626186	4.626186	12	.3855155	1.927577	4.240670	.4718618	27.03569	1.098934	62.96431
7000	2000	24000	108.8647	5.175263	5.175263	12	.4312719	2.156359	4.743991	.4718618	27.03569	1.098934	62.96431
10000	2000	24000	155.5210	5.828629	5.828629	12	.4857190	2.428595	5.342910	.4718618	27.03569	1.098934	62.96431
12000	2000	24000	186.6252	6.193842	6.193842	12	.5161535	2.580768	5.677689	.4718618	27.03569	1.098934	62.96431
15000	2000	24000	233.2815	6.672114	6.672114	12	.5560095	2.780048	6.116105	.4718618	27.03569	1.098934	62.96431
17000	2000	24000	264.3857	6.956370	6.956370	12	.5796975	2.898488	6.376673	.4718618	27.03569	1.098934	62.96431
20000	2000	24000	311.0420	7.343612	7.343612	12	.6119677	3.059838	6.731644	.4718618	27.03569	1.098934	62.96431
22000	2000	24000	342.1462	7.580664	7.580664	12	.6317220	3.158610	6.948942	.4718618	27.03569	1.098934	62.96431
25000	2000	24000	388.8025	7.910666	7.910666	12	.6592222	3.296111	7.251444	.4718618	27.03569	1.098934	62.96431
CASE 3: FLANGE : DIAMETER RATIO = 14													
500	2000	24000	7.776050	2.147285	2.147285	14	.1533775	.9202651	1.993908	.4797286	27.48643	1.091068	62.51357
1000	2000	24000	15.55210	2.705410	2.705410	14	.1932436	1.159461	2.512166	.4797286	27.48643	1.091068	62.51357
2000	2000	24000	31.10420	3.408603	3.408603	14	.2434716	1.460830	3.165131	.4797286	27.48643	1.091068	62.51357
5000	2000	24000	77.76050	4.626186	4.626186	14	.3304418	1.982651	4.295744	.4797286	27.48643	1.091068	62.51357
7000	2000	24000	108.8647	5.175263	5.175263	14	.3696616	2.217970	4.805601	.4797286	27.48643	1.091068	62.51357
10000	2000	24000	155.5210	5.828629	5.828629	14	.4163306	2.497984	5.412298	.4797286	27.48643	1.091068	62.51357
12000	2000	24000	186.6252	6.193842	6.193842	14	.4424173	2.654504	5.751425	.4797286	27.48643	1.091068	62.51357
15000	2000	24000	233.2815	6.672114	6.672114	14	.4765796	2.859477	6.195535	.4797286	27.48643	1.091068	62.51357
17000	2000	24000	264.3857	6.956370	6.956370	14	.4968836	2.981302	6.459487	.4797286	27.48643	1.091068	62.51357
20000	2000	24000	311.0420	7.343612	7.343612	14	.5245437	3.147262	6.819068	.4797286	27.48643	1.091068	62.51357
22000	2000	24000	342.1462	7.580664	7.580664	14	.5414760	3.248856	7.039188	.4797286	27.48643	1.091068	62.51357
25000	2000	24000	388.8025	7.910666	7.910666	14	.5650476	3.390285	7.345618	.4797286	27.48643	1.091068	62.51357
CASE 4: FLANGE : DIAMETER RATIO = 16													
500	2000	24000	7.776050	2.147285	2.147285	16	.1342053	.9394372	2.013080	.4855181	27.81814	1.085278	62.18186
1000	2000	24000	15.55210	2.705410	2.705410	16	.1690881	1.183617	2.536322	.4855181	27.81814	1.085278	62.18186
2000	2000	24000	31.10420	3.408603	3.408603	16	.2130377	1.491264	3.195565	.4855181	27.81814	1.085278	62.18186
5000	2000	24000	77.76050	4.626186	4.626186	16	.2891366	2.023956	4.337049	.4855181	27.81814	1.085278	62.18186
7000	2000	24000	108.8647	5.175263	5.175263	16	.3234539	2.264177	4.851809	.4855181	27.81814	1.085278	62.18186
10000	2000	24000	155.5210	5.828629	5.828629	16	.3642893	2.550025	5.464339	.4855181	27.81814	1.085278	62.18186
12000	2000	24000	186.6252	6.193842	6.193842	16	.3871151	2.709806	5.806727	.4855181	27.81814	1.085278	62.18186
15000	2000	24000	233.2815	6.672114	6.672114	16	.4170071	2.919050	6.255107	.4855181	27.81814	1.085278	62.18186
17000	2000	24000	264.3857	6.956370	6.956370	16	.4347731	3.043412	6.521597	.4855181	27.81814	1.085278	62.18186
20000	2000	24000	311.0420	7.343612	7.343612	16	.4589757	3.212830	6.884636	.4855181	27.81814	1.085278	62.18186
22000	2000	24000	342.1462	7.580664	7.580664	16	.4737915	3.316541	7.106873	.4855181	27.81814	1.085278	62.18186
25000	2000	24000	388.8025	7.910666	7.910666	16	.4944166	3.460916	7.416249	.4855181	27.81814	1.085278	62.18186

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Spreadsheet to Compute Parameters for Cylindrical Buoys with Dished and Flanged End Bells

Crown Radius and Flange:Diameter Ratio Are Assigned.

Crown center offset ft h	Bell Height ft C	Crown Volume cu ft Vc	Flange Disk Volume cu ft Vf	End Bell Volume cu ft Ve	Volume Cylinder Section cu ft Vcl	Cylinder Length ft Lc	Buoy Total Length ft Lb	Knuckle Stress Correct factor M	Buoy Working Pressure psi P	End Bell Thickn's in te	Cyl Wall Thickn's in tc	- - - parameters 11	cl
CASE 1: (continued)													
1.731197	.4160885	1.092477	.6891304	1.781608	4.212835	1.163336	1.995513	1.540569	892	.3598812	.4718300	.9889407	.9802237
2.181171	.5242387	2.184954	1.378261	3.563215	8.425669	1.465711	2.514189	1.540569	892	.4534219	.5944686	1.245987	1.235004
2.748103	.6604993	4.369909	2.756521	7.126430	16.85134	1.846680	3.167679	1.540569	892	.5712758	.7489835	1.569846	1.556008
3.729750	.8964355	10.92477	6.891304	17.81608	42.12835	2.506331	4.299202	1.540569	892	.7753406	1.016527	2.130608	2.111828
4.172430	1.002833	15.29468	9.647825	24.94251	58.97968	2.803805	4.809470	1.540569	892	.8673649	1.137178	2.383488	2.362479
4.699191	1.129438	21.84954	13.78261	35.63215	84.25669	3.157779	5.416655	1.540569	892	.9768679	1.280744	2.684398	2.660736
4.993635	1.200207	26.21945	16.53913	42.75858	101.1080	3.355641	5.756055	1.540569	892	1.038077	1.360993	2.852599	2.827454
5.379230	1.292884	32.77432	20.67391	53.44823	126.3850	3.614755	6.200522	1.540569	892	1.118235	1.466086	3.072869	3.045783
5.608405	1.347965	37.14423	23.43043	60.57466	143.2364	3.768756	6.464687	1.540569	892	1.165875	1.528546	3.203784	3.175544
5.920609	1.423003	43.69909	27.56521	71.26430	168.5134	3.978552	6.824558	1.540569	892	1.230776	1.613636	3.382130	3.352318
6.111727	1.468937	48.06900	30.32174	78.39073	185.3647	4.106981	7.044855	1.540569	892	1.270506	1.665724	3.491305	3.460531
6.377783	1.532883	54.62386	34.45652	89.08038	210.6417	4.285766	7.351532	1.540569	892	1.325814	1.738237	3.643289	3.611175
CASE 2: (continued)													
1.753251	.3940342	.9833210	.5729524	1.556273	4.663503	1.287784	2.075852	1.616025	892	.3769922	.4718300	1.013222	1.003848
2.208958	.4964519	1.966642	1.145905	3.112547	9.327006	1.622506	2.615410	1.616025	892	.4749804	.5944686	1.276580	1.264769
2.783112	.6254902	3.933284	2.291810	6.225094	18.65401	2.044229	3.295210	1.616025	892	.5984377	.7489835	1.608390	1.593510
3.777265	.8489209	9.833210	5.729524	15.56273	46.63503	2.774446	4.472288	1.616025	892	.8122050	1.016527	2.182920	2.162725
4.225584	.9496784	13.76649	8.021333	21.78783	65.28904	3.103742	5.003099	1.616025	892	.9086047	1.137178	2.442009	2.419417
4.759055	1.069573	19.66642	11.45905	31.12547	93.27006	3.495583	5.634729	1.616025	892	1.023314	1.280744	2.750307	2.724863
5.057251	1.136591	23.59970	13.75086	37.35056	111.9241	3.714611	5.987794	1.616025	892	1.087434	1.360993	2.922638	2.895599
5.447758	1.224356	29.49963	17.18857	46.68820	139.9051	4.001444	6.450155	1.616025	892	1.171402	1.466086	3.148316	3.119190
5.679853	1.276518	33.43291	19.48038	52.91330	158.5591	4.171919	6.724955	1.616025	892	1.221308	1.528546	3.282446	3.252078
5.996034	1.347578	39.33284	22.91810	62.25094	186.5401	4.404159	7.099314	1.616025	892	1.289295	1.613636	3.465170	3.433112
6.189587	1.391078	43.26612	25.20990	68.47603	205.1941	4.546325	7.328481	1.616025	892	1.330914	1.665724	3.577026	3.543934
6.459032	1.451634	49.16605	28.64762	77.81367	233.1751	4.744236	7.647504	1.616025	892	1.388851	1.738237	3.732741	3.698208
CASE 3: (continued)													
1.768836	.3784494	.9094125	.4900971	1.399510	4.977030	1.374362	2.131260	1.685414	892	.3926861	.4718300	1.030114	1.020265
2.228593	.4768164	1.818825	.9801943	2.799019	9.954061	1.731587	2.685220	1.685414	892	.4947535	.5944686	1.297863	1.285453
2.807852	.6007510	3.637650	1.960389	5.598039	19.90812	2.181663	3.383165	1.685414	892	.6233503	.7489835	1.635204	1.619569
3.810841	.8153445	9.094125	4.900971	13.99510	49.77030	2.960972	4.591661	1.685414	892	.8460165	1.016527	2.219314	2.198094
4.263146	.9121169	12.73177	6.861360	19.59313	69.67843	3.312407	5.136641	1.685414	892	.9464293	1.137178	2.482722	2.458983
4.801359	1.027270	18.18825	9.801943	27.99019	99.54061	3.730591	5.785131	1.685414	892	1.065914	1.280744	2.796160	2.769424
5.102205	1.091637	21.82590	11.76233	33.58823	119.4487	3.964345	6.147619	1.685414	892	1.132703	1.360993	2.971363	2.942952
5.496184	1.175930	27.28237	14.70291	41.98529	149.3109	4.270461	6.622321	1.685414	892	1.220167	1.466086	3.200804	3.170199
5.730341	1.226029	30.92002	16.66330	47.58333	169.2190	4.452398	6.904456	1.685414	892	1.272150	1.528546	3.337170	3.305261
6.049333	1.294279	36.37650	19.60389	55.98039	199.0812	4.700250	7.288808	1.685414	892	1.342967	1.613636	3.522941	3.489256
6.244606	1.336058	40.01415	21.56427	61.57842	218.9893	4.851975	7.524091	1.685414	892	1.386319	1.665724	3.636662	3.601890
6.516447	1.394220	45.47062	24.50486	69.97548	248.8515	5.063191	7.851630	1.685414	892	1.446668	1.738237	3.794973	3.758687
CASE 4: (continued)													
1.780435	.3668504	.8561565	.4280861	1.284243	5.207565	1.438021	2.171722	1.75	892	.4072583	.4718300	1.042546	1.032336
2.243207	.4622025	1.712313	.8561723	2.568485	10.41513	1.811793	2.736198	1.75	892	.5131133	.5944686	1.313525	1.300662
2.826264	.5823386	3.424626	1.712345	5.136970	20.83026	2.282717	3.447394	1.75	892	.6464822	.7489835	1.654938	1.638731
3.835830	.7903551	8.561565	4.280861	12.84243	52.07565	3.098123	4.678833	1.75	892	.8774114	1.016527	2.246097	2.224101
4.291101	.8841615	11.98619	5.993206	17.97940	72.90590	3.465836	5.234159	1.75	892	.9815504	1.137178	2.512684	2.488077
4.832844	.9957851	17.12313	8.561723	25.68485	104.1513	3.903391	5.894961	1.75	892	1.105469	1.280744	2.829905	2.802191
5.135663	1.058180	20.54776	10.27407	30.82182	124.9815	4.147971	6.264331	1.75	892	1.174736	1.360993	3.007223	2.977773
5.532225	1.139889	25.68469	12.84258	38.52728	156.2269	4.468267	6.748046	1.75	892	1.265446	1.466086	3.239432	3.207708
5.767918	1.188453	29.10932	14.55493	43.66425	177.0572	4.658631	7.035537	1.75	892	1.319359	1.528546	3.377444	3.344368
6.089001	1.254611	34.24626	17.12345	51.36970	208.3026	4.917964	7.427185	1.75	892	1.392804	1.613636	3.565457	3.530540
6.285555	1.295110	37.67089	18.83579	56.50668	229.1328	5.076716	7.666936	1.75	892	1.437764	1.665724	3.680550	3.644506
6.559178	1.351488	42.80782	21.40431	64.21213	260.3782	5.297716	8.000693	1.75	892	1.500352	1.738237	3.840772	3.803159

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Spreadsheet to Compute Parameters for Cylindrical Buoys with Dished and Flanged End Bells

Crown Radius and Flange:Diameter Ratio Are Assigned.

to calculate end bell surface area - - - - - - - - - - - - -							End Bells Surface Area sq ft	Cylinder Surface Area sq ft	End Bell Frontal Area sq ft	Cylinder Frontal Area sq ft	Buoy Frontal Area sq ft	End Bells Weight lb	Cylinder Wall Weight lb
d1	s1	l2	c2	d2	s2	X	Ae	Ac	Afe	Afc	Af	We	Wc
CASE 1: (continued)													
2.128358	.4857918	.2384007	.2263437	.2038688	1.032169	.5919209	9.129331	7.847741	.6621844	2.498014	3.822382	134.0474	151.0742
2.681563	.6120593	.3003660	.2851752	.2568585	1.300452	.7457737	14.49191	12.45751	1.051152	3.965349	6.067654	268.0947	302.1485
3.378558	.7711463	.3784375	.3592983	.3236215	1.638466	.9396159	23.00447	19.77507	1.668600	6.294600	9.631800	536.1895	604.2970
4.585408	1.046607	.5136187	.4876428	.4392219	2.223741	1.275255	42.37460	36.42599	3.073587	11.59475	17.74193	1340.474	1510.742
5.129645	1.170827	.5745796	.5455206	.4913527	2.487675	1.426614	53.03033	45.58585	3.846487	14.51043	22.20340	1876.663	2115.039
5.777252	1.318642	.6471190	.6143914	.5533849	2.801738	1.606721	67.26549	57.82265	4.879016	18.40552	28.16355	2680.947	3021.485
6.139246	1.401266	.6876666	.6528883	.5880593	2.977291	1.707395	75.95910	65.29584	5.509596	20.78431	31.80350	3217.137	3625.782
6.613303	1.509468	.7407664	.7033026	.6334676	3.207190	1.839236	88.14272	75.76911	6.393320	24.11806	36.90470	4021.421	4532.227
6.895053	1.573777	.7723257	.7332658	.6604556	3.343827	1.917594	95.81310	82.36271	6.949681	26.21686	40.11623	4557.611	5136.524
7.278881	1.661384	.8153189	.7740847	.6972213	3.529969	2.024341	106.7773	91.78774	7.744955	29.21694	44.70686	5361.895	6042.970
7.513845	1.715014	.8416375	.7990722	.7197277	3.643917	2.089687	113.7821	97.80922	8.253042	31.13364	47.63972	5898.084	6647.267
7.840937	1.789672	.8782756	.8338574	.7510589	3.802544	2.180655	123.9041	106.5102	8.987224	33.90326	51.87771	6702.369	7553.712
CASE 2: (continued)													
2.127420	.4972805	.1966438	.1868972	.1700713	1.039739	.5854483	8.900934	8.687254	.6246327	2.765239	4.014504	136.9078	167.2354
2.680381	.6265342	.2477557	.2354757	.2142764	1.309990	.7376187	14.12935	13.79016	.9915426	4.389543	6.372628	273.8155	334.4709
3.377068	.7893837	.3121526	.2966808	.2699713	1.650483	.9293413	22.42895	21.89051	1.573976	6.967965	10.11592	547.6311	668.9417
4.583387	1.071358	.4236562	.4026578	.3664074	2.240051	1.261310	41.31448	40.32266	2.899288	12.83510	18.63368	1369.078	1672.354
5.127384	1.198517	.4739396	.4504488	.4098959	2.505920	1.411014	51.70362	50.46240	3.628358	16.06268	23.31940	1916.709	2341.296
5.774705	1.349827	.5337734	.5073170	.4616444	2.822287	1.589151	65.58265	64.00824	4.602333	20.37445	29.57912	2738.155	3344.709
6.136540	1.434405	.5672189	.5391048	.4905704	2.999127	1.688725	74.05876	72.28087	5.197154	23.00771	33.40202	3285.786	4013.650
6.610387	1.545166	.6110180	.5807330	.5284510	3.230712	1.819124	85.93758	83.87452	6.030763	26.69809	38.75961	4107.233	5017.063
6.892014	1.610996	.6370496	.6054743	.5509649	3.368352	1.896625	93.41606	91.17347	6.555573	29.02142	42.13256	4654.864	5686.005
7.275673	1.700676	.6725124	.6391794	.5816356	3.555859	2.002205	104.1060	101.6067	7.305748	32.34243	46.95393	5476.311	6689.417
7.510532	1.755574	.6942211	.6598122	.6004108	3.670642	2.066837	110.9355	108.2724	7.785022	34.46417	50.03421	6023.942	7358.359
7.837481	1.831997	.7244420	.6885351	.6265479	3.830433	2.156810	120.8043	117.9042	8.477570	37.53007	54.48521	6845.388	8361.771
CASE 3: (continued)													
2.126754	.5052546	.1673452	.1591674	.1458822	1.044973	.5806803	8.737914	9.271299	.5969846	2.951146	4.145115	139.9953	178.4787
2.679542	.6365809	.2108418	.2005383	.1838001	1.316583	.7316114	13.87057	14.71727	.9476540	4.684652	6.579960	279.9906	356.9573
3.376011	.8020417	.2656440	.2526624	.2315736	1.658790	.9217726	22.01816	23.36221	1.504307	7.436422	10.44504	559.9812	713.9147
4.581952	1.088538	.3605344	.3429157	.3142937	2.251325	1.251038	40.55781	43.03356	2.770957	13.69801	19.23992	1399.953	1784.787
5.125779	1.217736	.4033258	.3836160	.3515969	2.518532	1.399522	50.75667	53.85499	3.467756	17.14258	24.07809	1959.934	2498.701
5.772898	1.371472	.4542449	.4320467	.3959852	2.836492	1.576209	64.38150	68.31151	4.398620	21.74423	30.54147	2799.906	3569.573
6.134619	1.457407	.4827072	.4591181	.4207971	3.014222	1.674972	72.70238	77.14031	4.967112	24.55452	34.48875	3359.887	4283.488
6.608318	1.569944	.5199806	.4945700	.4532899	3.246973	1.804309	84.36364	89.51341	5.763823	28.49300	40.02065	4199.859	5354.360
6.889856	1.636829	.5421336	.5156405	.4726017	3.385305	1.881179	91.70515	97.30307	6.265404	30.97253	43.50334	4759.840	6068.275
7.273395	1.727947	.5723127	.5443447	.4989101	3.573756	1.985899	102.1993	108.4378	6.982375	34.51681	48.48156	5599.812	7139.147
7.508181	1.783725	.5907870	.5619162	.5150150	3.689117	2.050004	108.9038	115.5515	7.440434	36.78119	51.66206	6159.793	7853.062
7.835027	1.861374	.6165052	.5863776	.5374346	3.849712	2.139245	118.5917	125.8309	8.102328	40.05321	56.25787	6999.765	8923.934
CASE 4: (continued)													
2.126257	.5111132	.1456501	.1386067	.1277153	1.048806	.5770240	8.615725	9.700742	.5758100	3.087842	4.239462	143.1601	186.7457
2.678915	.6439622	.1835076	.1746334	.1609112	1.321413	.7270047	13.67661	15.39897	.9140413	4.901644	6.729726	286.3202	373.4915
3.375222	.8113416	.2312051	.2200244	.2027354	1.664876	.9159686	21.71027	24.44434	1.450950	7.780874	10.68277	572.6403	746.9829
4.580881	1.101160	.3137936	.2986190	.2751543	2.259584	1.243161	39.99065	45.02685	2.672673	14.33249	19.67784	1431.601	1867.457
5.124581	1.231855	.3510375	.3340618	.3078121	2.527772	1.390710	50.04690	56.34953	3.344757	17.93661	24.62613	2004.241	2614.440
5.771548	1.387375	.3953552	.3762364	.3466727	2.846898	1.566284	63.48121	71.47567	4.242604	22.75141	31.23662	2863.202	3734.915
6.133185	1.474305	.4201276	.3998108	.3683947	3.025280	1.664425	71.68572	80.71342	4.790932	25.69188	35.27374	3435.842	4481.898
6.606774	1.588147	.4525688	.4306831	.3968412	3.258884	1.792948	83.18391	93.65963	5.559384	29.81279	40.93155	4294.802	5602.372
6.888246	1.655808	.4718498	.4490318	.4137481	3.397725	1.869334	90.42277	101.8101	6.043174	32.40716	44.49351	4867.443	6349.355
7.271695	1.747982	.4981164	.4740281	.4367803	3.586866	1.973394	100.7701	113.4606	6.734714	36.11562	49.58505	5726.403	7469.829
7.506426	1.804408	.5141956	.4893298	.4508796	3.702651	2.037096	107.3809	120.9038	7.176526	38.48488	52.83794	6299.043	8216.812
7.833196	1.882957	.5365796	.5106313	.4705073	3.863835	2.125775	116.9334	131.6593	7.814944	41.90846	57.53835	7158.004	9337.287

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Spreadsheet to Compute Parameters for Cylindrical Buoys with Dished and Flanged End Bells Crown Radius and Flange:Diameter Ratio Are Assigned.

Buoy Weight lb Wb	Net Buoyancy lb B	Efficeincy % E
CASE 1: (conclusion)		
285.1216	214.8784	42.98
570.2432	429.7568	42.98
1140.486	859.5135	42.98
2851.216	2148.784	42.98
3991.703	3008.297	42.98
5702.432	4297.568	42.98
6842.919	5157.081	42.98
8553.648	6446.352	42.98
9694.135	7305.865	42.98
11404.86	8595.135	42.98
12545.35	9454.649	42.98
14256.08	10743.92	42.98
CASE 2: (conclusion)		
304.1432	195.8568	39.17
608.2864	391.7136	39.17
1216.573	783.4272	39.17
3041.432	1958.568	39.17
4258.005	2741.995	39.17
6082.864	3917.136	39.17
7299.437	4700.563	39.17
9124.296	5875.704	39.17
10340.87	6659.131	39.17
12165.73	7834.272	39.17
13382.30	8617.699	39.17
15207.16	9792.840	39.17
CASE 3: (conclusion)		
318.4740	181.5260	36.31
636.9479	363.0521	36.31
1273.896	726.1041	36.31
3184.740	1815.260	36.31
4458.636	2541.364	36.31
6369.479	3630.521	36.31
7643.375	4356.625	36.31
9554.219	5445.781	36.31
10828.12	6171.885	36.31
12738.96	7261.041	36.31
14012.85	7987.145	36.31
15923.70	9076.301	36.31
CASE 4: (conclusiion)		
329.9058	170.0942	34.02
659.8116	340.1884	34.02
1319.623	680.3768	34.02
3299.058	1700.942	34.02
4618.681	2381.319	34.02
6598.116	3401.884	34.02
7917.739	4082.261	34.02
9897.174	5102.826	34.02
11216.80	5783.202	34.02
13196.23	6803.768	34.02
14515.86	7484.144	34.02
16495.29	8504.709	34.02

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Spreadsheet to Compute Parameters for Cylindrical Buoys with Dished and Flanged End Bells (continued—sheet 2 of 2)

Crown Radius and Flange:Diameter Ratio Are Assigned

Buoy Gross Displace- lb Dg	Buoy Working Depth ft d	Buoy Material Allowable Stress Sa	Buoy Volume cu ft Vb	Buoy Diam- eter ft Db	Bell Crown Radius ft Rc	Flange : Diameter ratio f	Flange Radius ft r	Flange Center Offset ft w	Flange Center Radius ft L	Crown Half Angle radians phi(r)	" " " degrees phi(d)	Flange Arc Angle radians theta(r)	" " " degrees theta(d)
CASE 5: FLANGE : DIAMETER RATIO = 16.66667 (1 / 0.06)													
500	2000	24000	7.776050	2.147285	2.147285	16.66667	.1288371	.9448055	2.018448	.4871226	27.91007	1.083674	62.08993
1000	2000	24000	15.55210	2.705410	2.705410	16.66667	.1623246	1.190380	2.543085	.4871226	27.91007	1.083674	62.08993
2000	2000	24000	31.10420	3.408603	3.408603	16.66667	.2045162	1.499785	3.204087	.4871226	27.91007	1.083674	62.08993
5000	2000	24000	77.76050	4.626186	4.626186	16.66667	.2775711	2.035522	4.348614	.4871226	27.91007	1.083674	62.08993
7000	2000	24000	108.8647	5.175263	5.175263	16.66667	.3105158	2.277116	4.864747	.4871226	27.91007	1.083674	62.08993
10000	2000	24000	155.5210	5.828629	5.828629	16.66667	.3497177	2.564597	5.478911	.4871226	27.91007	1.083674	62.08993
12000	2000	24000	186.6252	6.193842	6.193842	16.66667	.3716305	2.725291	5.822212	.4871226	27.91007	1.083674	62.08993
15000	2000	24000	233.2815	6.672114	6.672114	16.66667	.4003268	2.935730	6.271787	.4871226	27.91007	1.083674	62.08993
17000	2000	24000	264.3857	6.956370	6.956370	16.66667	.4173822	3.060803	6.538988	.4871226	27.91007	1.083674	62.08993
20000	2000	24000	311.0420	7.343612	7.343612	16.66667	.4406167	3.231189	6.902995	.4871226	27.91007	1.083674	62.08993
22000	2000	24000	342.1462	7.580664	7.580664	16.66667	.4548399	3.335492	7.125825	.4871226	27.91007	1.083674	62.08993
25000	2000	24000	388.8025	7.910666	7.910666	16.66667	.4746400	3.480693	7.436026	.4871226	27.91007	1.083674	62.08993
CASE 6: FLANGE : DIAMETER RATIO = 18													
500	2000	24000	7.776050	2.147285	2.147285	18	.1192936	.9543489	2.027992	.4899573	28.07249	1.080839	61.92751
1000	2000	24000	15.55210	2.705410	2.705410	18	.1503005	1.202404	2.555109	.4899573	28.07249	1.080839	61.92751
2000	2000	24000	31.10420	3.408603	3.408603	18	.1893668	1.514935	3.219236	.4899573	28.07249	1.080839	61.92751
5000	2000	24000	77.76050	4.626186	4.626186	18	.2570103	2.056082	4.369175	.4899573	28.07249	1.080839	61.92751
7000	2000	24000	108.8647	5.175263	5.175263	18	.2875146	2.300117	4.887748	.4899573	28.07249	1.080839	61.92751
10000	2000	24000	155.5210	5.828629	5.828629	18	.3238127	2.590502	5.504816	.4899573	28.07249	1.080839	61.92751
12000	2000	24000	186.6252	6.193842	6.193842	18	.3441023	2.752819	5.849740	.4899573	28.07249	1.080839	61.92751
15000	2000	24000	233.2815	6.672114	6.672114	18	.3706730	2.965384	6.301441	.4899573	28.07249	1.080839	61.92751
17000	2000	24000	264.3857	6.956370	6.956370	18	.3864650	3.091720	6.569905	.4899573	28.07249	1.080839	61.92751
20000	2000	24000	311.0420	7.343612	7.343612	18	.4079784	3.263827	6.935633	.4899573	28.07249	1.080839	61.92751
22000	2000	24000	342.1462	7.580664	7.580664	18	.4211480	3.369184	7.159516	.4899573	28.07249	1.080839	61.92751
25000	2000	24000	388.8025	7.910666	7.910666	18	.4394814	3.515852	7.471185	.4899573	28.07249	1.080839	61.92751
CASE 7: FLANGE : DIAMETER RATIO = 20													
500	2000	24000	7.776050	2.147285	2.147285	20	.1073643	.9662783	2.039921	.4934694	28.27371	1.077327	61.72629
1000	2000	24000	15.55210	2.705410	2.705410	20	.1352705	1.217434	2.570139	.4934694	28.27371	1.077327	61.72629
2000	2000	24000	31.10420	3.408603	3.408603	20	.1704301	1.533871	3.238173	.4934694	28.27371	1.077327	61.72629
5000	2000	24000	77.76050	4.626186	4.626186	20	.2313093	2.081784	4.394876	.4934694	28.27371	1.077327	61.72629
7000	2000	24000	108.8647	5.175263	5.175263	20	.2587631	2.328868	4.916500	.4934694	28.27371	1.077327	61.72629
10000	2000	24000	155.5210	5.828629	5.828629	20	.2914314	2.622883	5.537197	.4934694	28.27371	1.077327	61.72629
12000	2000	24000	186.6252	6.193842	6.193842	20	.3096921	2.787229	5.884150	.4934694	28.27371	1.077327	61.72629
15000	2000	24000	233.2815	6.672114	6.672114	20	.3336057	3.002451	6.338508	.4934694	28.27371	1.077327	61.72629
17000	2000	24000	264.3857	6.956370	6.956370	20	.3478185	3.130367	6.608552	.4934694	28.27371	1.077327	61.72629
20000	2000	24000	311.0420	7.343612	7.343612	20	.3671806	3.304625	6.976431	.4934694	28.27371	1.077327	61.72629
22000	2000	24000	342.1462	7.580664	7.580664	20	.3790332	3.411299	7.201631	.4934694	28.27371	1.077327	61.72629
25000	2000	24000	388.8025	7.910666	7.910666	20	.3955333	3.559800	7.515133	.4934694	28.27371	1.077327	61.72629
CASE 8: FLANGE : DIAMETER RATIO = 22													
500	2000	24000	7.776050	2.147285	2.147285	22	.0976039	.9760387	2.049681	.4963174	28.43689	1.074479	61.56311
1000	2000	24000	15.55210	2.705410	2.705410	22	.1229732	1.229732	2.582437	.4963174	28.43689	1.074479	61.56311
2000	2000	24000	31.10420	3.408603	3.408603	22	.1549365	1.549365	3.253666	.4963174	28.43689	1.074479	61.56311
5000	2000	24000	77.76050	4.626186	4.626186	22	.2102812	2.102812	4.415904	.4963174	28.43689	1.074479	61.56311
7000	2000	24000	108.8647	5.175263	5.175263	22	.2352392	2.352392	4.940023	.4963174	28.43689	1.074479	61.56311
10000	2000	24000	155.5210	5.828629	5.828629	22	.2649377	2.649377	5.563691	.4963174	28.43689	1.074479	61.56311
12000	2000	24000	186.6252	6.193842	6.193842	22	.2815383	2.815383	5.912304	.4963174	28.43689	1.074479	61.56311
15000	2000	24000	233.2815	6.672114	6.672114	22	.3032779	3.032779	6.368836	.4963174	28.43689	1.074479	61.56311
17000	2000	24000	264.3857	6.956370	6.956370	22	.3161986	3.161986	6.640172	.4963174	28.43689	1.074479	61.56311
20000	2000	24000	311.0420	7.343612	7.343612	22	.3338005	3.338005	7.009811	.4963174	28.43689	1.074479	61.56311
22000	2000	24000	342.1462	7.580664	7.580664	22	.3445757	3.445757	7.236089	.4963174	28.43689	1.074479	61.56311
25000	2000	24000	388.8025	7.910666	7.910666	22	.3595757	3.595757	7.551090	.4963174	28.43689	1.074479	61.56311

7 August 1990

Spreadsheet to Compute Parameters for Cylindrical Buoys with Dished and Flanged End Bells (continued—sheet 2 of 2)

Crown Radius and Flange:Diameter Ratio Are Assigned

Crown center offset ft h	Bell Height ft C	Crown Volume cu ft Vc	Flange Disk Volume cu ft Vf	End Bell Volume cu ft Ve	Volume Cylinder Section cu ft Vcl	Cylinder Length ft Lc	Buoy Total Length ft Lb	Knuckle Stress Correct factor M	Buoy Working Pressure psi P	End Bell Thickn's in te	Cyl Wall Thickn's in tc	parameters to calc ll	cl
CASE 5: (continued)													
1.783669	.3636161	.8415748	.4107486	1.252323	5.271403	1.455650	2.182882	1.770621	892	.4119037	.4718300	1.045991	1.035680
2.247282	.4581276	1.683150	.8214971	2.504647	10.54281	1.834004	2.750259	1.770621	892	.5189661	.5944686	1.317866	1.304875
2.831398	.5772046	3.366299	1.642994	5.009293	21.08561	2.310700	3.465109	1.770621	892	.6538564	.7489835	1.660407	1.644039
3.842798	.7833872	8.415748	4.107486	12.52323	52.71403	3.136102	4.702877	1.770621	892	.8874196	1.016527	2.253519	2.231305
4.298896	.8763666	11.78205	5.750480	17.53253	73.79964	3.508323	5.261056	1.770621	892	.9927465	1.137178	2.520987	2.496136
4.841623	.9870061	16.83150	8.214971	25.04647	105.4281	3.951242	5.925254	1.770621	892	1.118079	1.280744	2.839257	2.811268
5.144992	1.048850	20.19779	9.857965	30.05576	126.5137	4.198821	6.296522	1.770621	892	1.188136	1.360993	3.017160	2.987418
5.542274	1.129840	25.24724	12.32246	37.56970	158.1421	4.523042	6.782722	1.770621	892	1.279881	1.466086	3.250138	3.218099
5.778395	1.177975	28.61354	13.96545	42.57899	179.2277	4.715740	7.071691	1.770621	892	1.334408	1.528546	3.388605	3.355201
6.100062	1.243550	33.66299	16.42994	50.09293	210.8561	4.978252	7.465352	1.770621	892	1.408691	1.613636	3.577239	3.541976
6.296973	1.283692	37.02929	18.07294	55.10223	231.9417	5.138951	7.706334	1.770621	892	1.454164	1.665724	3.692713	3.656311
6.571093	1.339573	42.07874	20.53743	62.61617	263.5702	5.362660	8.041806	1.770621	892	1.517466	1.738237	3.853464	3.815478
CASE 6: (continued)													
1.789404	.3578809	.8160052	.3799577	1.195963	5.384124	1.486777	2.202538	1.810660	892	.4209139	.4718300	1.052078	1.041586
2.254508	.4509016	1.632010	.7599153	2.391926	10.76825	1.873221	2.775024	1.810660	892	.5303182	.5944686	1.325535	1.312316
2.840502	.5681004	3.264021	1.519831	4.783852	21.53650	2.360111	3.496312	1.810660	892	.6681591	.7489835	1.670070	1.653415
3.855155	.7710309	8.160052	3.799577	11.95963	53.84124	3.203163	4.745225	1.810660	892	.9068314	1.016527	2.266634	2.244030
4.312719	.8625438	11.42407	5.319407	16.74348	75.37774	3.583343	5.308431	1.810660	892	1.014462	1.137178	2.535658	2.510371
4.857190	.9714381	16.32010	7.599153	23.91926	107.6825	4.035733	5.978609	1.810660	892	1.142536	1.280744	2.855779	2.827300
5.161535	1.032307	19.58413	9.118984	28.70311	129.2190	4.288606	6.353220	1.810660	892	1.214126	1.360993	3.034718	3.004455
5.560095	1.112019	24.48016	11.39873	35.87889	161.5237	4.619761	6.843799	1.810660	892	1.307877	1.466086	3.269051	3.236451
5.796975	1.159395	27.74418	12.91856	40.66274	183.0602	4.816579	7.135369	1.810660	892	1.363597	1.528546	3.408325	3.374335
6.119677	1.223935	32.64021	15.19831	47.83852	215.3650	5.084705	7.532575	1.810660	892	1.439505	1.613636	3.598056	3.562175
6.317220	1.263444	35.90423	16.71814	52.62237	236.9015	5.248840	7.775728	1.810660	892	1.485973	1.665724	3.714202	3.677162
6.592222	1.318444	40.80026	18.99788	59.79814	269.2062	5.477332	8.114221	1.810660	892	1.550660	1.738237	3.875889	3.837237
CASE 7: (continued)													
1.796548	.3507375	.7846754	.3415310	1.126206	5.523637	1.525302	2.226777	1.868034	892	.4338021	.4718300	1.059619	1.048901
2.263508	.4419016	1.569351	.6830621	2.252413	11.04727	1.921760	2.805563	1.868034	892	.5465564	.5944686	1.335037	1.321532
2.851842	.5567611	3.138701	1.366124	4.504826	22.09455	2.421266	3.534788	1.868034	892	.6886180	.7489835	1.682041	1.665026
3.870545	.7556410	7.846754	3.415310	11.26206	55.23637	3.286163	4.797445	1.868034	892	.9345984	1.016527	2.282881	2.259789
4.329935	.8453273	10.98546	4.781434	15.76689	77.33092	3.676195	5.366849	1.868034	892	1.045525	1.137178	2.553834	2.528000
4.876581	.9520480	15.69351	6.830621	22.52413	110.4727	4.140306	6.044402	1.868034	892	1.177520	1.280744	2.876250	2.847155
5.182140	1.011702	18.83221	8.196745	27.02895	132.5673	4.399732	6.423136	1.868034	892	1.251302	1.360993	3.056472	3.025554
5.582291	1.089823	23.54026	10.24593	33.78619	165.7091	4.739468	6.919114	1.868034	892	1.347924	1.466086	3.292484	3.259179
5.820117	1.136253	26.67896	11.61205	38.29102	187.8037	4.941386	7.213893	1.868034	892	1.405351	1.528546	3.432756	3.398032
6.144106	1.199505	31.38701	13.66124	45.04826	220.9455	5.216459	7.615470	1.868034	892	1.483582	1.613636	3.623848	3.587191
6.342439	1.238226	34.52572	15.02737	49.55308	243.0400	5.384847	7.861298	1.868034	892	1.531473	1.665724	3.740826	3.702986
6.618538	1.292128	39.23377	17.07655	56.31032	276.1818	5.619260	8.203516	1.868034	892	1.598141	1.738237	3.903672	3.864184
CASE 8: (continued)													
1.802371	.3449140	.7595603	.3101474	1.069708	5.636634	1.556505	2.246333	1.922604	892	.4460359	.4718300	1.065735	1.054830
2.270845	.4345644	1.519121	.6202948	2.139415	11.27327	1.961074	2.830202	1.922604	892	.5619700	.5944686	1.342742	1.329003
2.861086	.5475168	3.038241	1.240590	4.278831	22.54654	2.470798	3.565831	1.922604	892	.7080378	.7489835	1.691749	1.674438
3.883091	.7430947	7.595603	3.101474	10.69708	56.36634	3.353389	4.839578	1.922604	892	.9609551	1.016527	2.296056	2.272562
4.343971	.8312918	10.63384	4.342064	14.97591	78.91288	3.751399	5.413982	1.922604	892	1.075010	1.137178	2.568573	2.542290
4.892388	.9362406	15.19121	6.202948	21.39415	112.7327	4.225005	6.097486	1.922604	892	1.210728	1.280744	2.892850	2.863249
5.198938	.9949041	18.22945	7.443538	25.67298	135.2792	4.489738	6.479546	1.922604	892	1.286590	1.360993	3.074111	3.042656
5.600386	1.071728	22.78681	9.304422	32.09123	169.0990	4.836423	6.979879	1.922604	892	1.385937	1.466086	3.311486	3.277602
5.838983	1.117387	25.82505	10.54501	36.37006	191.6456	5.042472	7.277247	1.922604	892	1.444983	1.528546	3.452567	3.417240
6.164023	1.179589	30.38241	12.40590	42.78831	225.4654	5.323173	7.682351	1.922604	892	1.525421	1.613636	3.644762	3.607468
6.362998	1.217667	33.42065	13.64649	47.06714	248.0119	5.495005	7.930338	1.922604	892	1.574662	1.665724	3.762415	3.723917
6.639992	1.270674	37.97801	15.50737	53.48538	281.8317	5.734214	8.275562	1.922604	892	1.643210	1.738237	3.926201	3.886027

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Spreadsheet to Compute Parameters for Cylindrical Buoys with Dished and Flanged End Bells (continued—sheet 2 of 2)

Crown Radius and Flange:Diameter Ratio Are Assigned

ulate end bell surface area - - - -						- - - -	-End Bells Surface Area sq ft	Cylinder Surface Area sq ft	End Bell Frontal Area sq ft	Cylinder Frontal Area sq ft	Buoy Frontal Area sq ft	End Bells Weight lb	Cylinder Wall Weight lb
d1	s1	12	c2	d2	s2	X	Ae	Ac	Afe	Afc	Af	We	Wc
CASE 5: (continued)													
2.126118	.5127353	.1396174	.1328853	.1226248	1.049866	.5759878	8.581525	9.819661	.5698149	3.125695	4.265325	144.2183	189.0350
2.678741	.6460060	.1759069	.1674250	.1544976	1.322748	.7256992	13.62232	15.58774	.9045247	4.961732	6.770781	288.4366	378.0700
3.375002	.8139165	.2216288	.2109423	.1946548	1.666558	.9143237	21.62409	24.74400	1.435843	7.876258	10.74795	576.8731	756.1401
4.580582	1.104655	.3007965	.2862928	.2641872	2.261867	1.240928	39.83191	45.57883	2.644846	14.50819	19.79788	1442.183	1890.350
5.124246	1.235765	.3364978	.3202725	.2955433	2.530326	1.388213	49.84824	57.04031	3.309932	18.15649	24.77636	2019.056	2646.490
5.771172	1.391778	.3789799	.3607063	.3328550	2.849774	1.563472	63.22922	72.35188	4.198432	23.03032	31.42718	2884.366	3780.700
6.132785	1.478984	.4027262	.3833076	.3537113	3.028337	1.661436	71.40116	81.70287	4.741051	26.00683	35.48893	3461.239	4536.840
6.606342	1.593188	.4338237	.4129056	.3810239	3.262177	1.789728	82.85371	94.80779	5.501502	30.17826	41.18126	4326.548	5671.050
6.887796	1.661063	.4523061	.4304969	.3972569	3.401158	1.865977	90.06383	103.0582	5.980255	32.80444	44.76495	4903.421	6427.191
7.271220	1.753530	.4774847	.4544614	.4193711	3.590491	1.969851	100.3701	114.8515	6.664595	36.55835	49.88754	5768.731	7561.401
7.505936	1.810134	.4928980	.4691315	.4329084	3.706392	2.033438	106.9546	122.3860	7.101807	38.95666	53.16028	6345.604	8317.541
7.832685	1.888933	.5143549	.4895537	.4517538	3.867739	2.121957	116.4692	133.2733	7.733577	42.42221	57.88937	7210.914	9451.751
CASE 6: (continued)													
2.125871	.5155996	.1289372	.1227521	.1135711	1.051735	.5741321	8.520738	10.02964	.5590862	3.192533	4.310706	146.3291	193.0772
2.678430	.6496147	.1624507	.1546580	.1430907	1.325104	.7233611	13.52583	15.92106	.8874941	5.067831	6.842819	292.6581	386.1545
3.374611	.8184633	.2046750	.1948568	.1802830	1.669526	.9113779	21.47091	25.27311	1.408809	8.044680	10.86230	585.3163	772.3090
4.580051	1.110826	.2777868	.2644614	.2446816	2.265895	1.236930	39.54976	46.55346	2.595048	14.81843	20.00852	1463.291	1930.772
5.123653	1.242668	.3107570	.2958501	.2737226	2.534832	1.383740	49.49514	58.26003	3.247612	18.54474	25.03997	2048.607	2703.081
5.770503	1.399553	.3499894	.3332005	.3082795	2.854849	1.558434	62.78134	73.89902	4.119383	23.52279	31.76155	2926.581	3861.545
6.132074	1.487246	.3719192	.3540784	.3275959	3.033730	1.656084	70.89540	83.44996	4.651785	26.56295	35.86652	3511.898	4633.854
6.605577	1.602088	.4006378	.3814194	.3528919	3.267986	1.783962	82.26682	96.83511	5.397918	30.82357	41.61941	4389.872	5792.317
6.886998	1.670342	.4177065	.3976692	.3679264	3.407214	1.859965	89.42587	105.2619	5.867657	33.50591	45.24122	4975.188	6564.626
7.270378	1.763326	.4409590	.4198063	.3884078	3.595884	1.963504	99.65916	117.3074	6.539112	37.34010	50.41832	5853.163	7723.090
7.505067	1.820246	.4551932	.4333577	.4009457	3.712992	2.026886	106.1970	125.0030	6.968093	39.78969	53.72588	6438.479	8495.399
7.831777	1.899485	.4750087	.4522227	.4183997	3.874626	2.115121	115.6442	136.1232	7.587968	43.32935	58.50528	7316.453	9653.862
CASE 7: (continued)													
2.125564	.5191454	.1156664	.1101534	.1022470	1.054047	.5717880	8.444781	10.28953	.5455494	3.275258	4.366357	149.4653	198.0802
2.678043	.6540822	.1457305	.1387846	.1288231	1.328015	.7204077	13.40525	16.33361	.8660057	5.199148	6.931160	298.9305	396.1605
3.374123	.8240919	.1836090	.1748576	.1623069	1.673195	.9076568	21.27952	25.92798	1.374698	8.253133	11.00253	597.8610	792.3210
4.579389	1.118465	.2491957	.2373183	.2202844	2.270875	1.231880	39.19720	47.75975	2.532216	15.20240	20.26683	1494.653	1980.802
5.122912	1.251214	.2787725	.2654854	.2464297	2.540402	1.378090	49.05393	59.76966	3.168980	19.02527	25.36323	2092.514	2773.123
5.769669	1.409177	.3139669	.2990023	.2775409	2.861123	1.552071	62.22168	75.81388	4.019642	24.13231	32.17159	2989.305	3961.605
6.131188	1.497474	.3336396	.3177374	.2949313	3.040396	1.649322	70.26341	85.61231	4.539154	27.25125	36.32955	3587.166	4753.926
6.604622	1.613105	.3594024	.3422722	.3177051	3.275168	1.776678	81.53347	99.34429	5.267221	31.62227	42.15671	4483.958	5942.407
6.886003	1.681830	.3747143	.3568543	.3312405	3.414702	1.852371	88.62869	107.9895	5.725587	34.37411	45.82529	5081.819	6734.728
7.269328	1.775452	.3955735	.3767193	.3496797	3.604789	1.955487	98.77076	120.3470	6.380784	38.30765	51.06922	5978.610	7923.210
7.503982	1.832764	.4083427	.3888799	.3609674	3.721152	2.018611	105.2503	128.2421	6.799378	40.82072	54.41948	6576.471	8715.531
7.830646	1.912548	.4261187	.4058086	.3766810	3.883141	2.106485	114.6133	139.6504	7.404244	44.45209	59.26058	7473.263	9904.012
CASE 8: (continued)													
2.125314	.5220184	.1048733	.0999007	.0929760	1.055917	.5698497	8.382657	10.50002	.5343707	3.342260	4.411002	152.5498	202.1324
2.677727	.6577020	.1321321	.1258671	.1171424	1.330372	.7179656	13.30664	16.66774	.8482607	5.305507	7.002029	305.0996	404.2648
3.373725	.8286525	.1664760	.1585825	.1475902	1.676163	.9045800	21.12297	26.45839	1.346530	8.421968	11.11503	610.1992	808.5295
4.578849	1.124655	.2259427	.2152296	.2003107	2.274903	1.227704	38.90885	48.73678	2.480329	15.51340	20.47406	1525.498	2021.324
5.122308	1.258139	.2527596	.2407750	.2240854	2.544909	1.373419	48.69306	60.99237	3.104045	19.41447	25.62256	2135.697	2829.853
5.768989	1.416976	.2846699	.2711723	.2523757	2.866199	1.546810	61.76395	77.36481	3.937277	24.62598	32.50054	3050.996	4042.648
6.130465	1.505762	.3025070	.2881636	.2681892	3.045791	1.643731	69.74652	87.36369	4.446144	27.80873	36.70101	3661.195	4851.177
6.603844	1.622033	.3258657	.3104148	.2888980	3.280979	1.770655	80.93367	101.3766	5.159293	32.26917	42.58775	4576.494	6063.971
6.885191	1.691137	.3397488	.3236396	.3012061	3.420760	1.846092	87.97670	110.1986	5.608266	35.07730	46.29384	5186.693	6872.501
7.268470	1.785278	.3586617	.3416557	.3179734	3.611184	1.948858	98.04416	122.8090	6.250038	39.09131	51.59139	6101.992	8085.295
7.503097	1.842907	.3702393	.3526844	.3282376	3.727754	2.011768	104.4761	130.8655	6.660054	41.65579	54.97590	6712.192	8893.825
7.829722	1.923132	.3863566	.3680375	.3425265	3.890030	2.099344	113.7702	142.5072	7.252527	45.36145	59.86650	7627.490	10106.62

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Spreadsheet to Compute Parameters for Cylindrical Buoys with Dished and Flanged End Bells (continued—sheet 2 of 2)

Crown Radius and Flange:Diameter Ratio Are Assigned

Buoy Weight lb Wb	Net Buoyancy lb B	Effic-eincy % E
CASE 5: (conclusion)		
333.2533	166.7467	33.35
666.5066	333.4934	33.35
1333.013	666.9868	33.35
3332.533	1667.467	33.35
4665.546	2334.454	33.35
6665.066	3334.934	33.35
7998.079	4001.921	33.35
9997.599	5002.401	33.35
11330.61	5669.388	33.35
13330.13	6669.868	33.35
14663.14	7336.855	33.35
16662.66	8337.335	33.35
CASE 6: (conclusion)		
339.4063	160.5937	32.12
678.8126	321.1874	32.12
1357.625	642.3748	32.12
3394.063	1605.937	32.12
4751.688	2248.312	32.12
6788.126	3211.874	32.12
8145.751	3854.249	32.12
10182.19	4817.811	32.12
11539.81	5460.186	32.12
13576.25	6423.748	32.12
14933.88	7066.122	32.12
16970.32	8029.685	32.12
CASE 7: (conclusion)		
347.5455	152.4545	30.49
695.0910	304.9090	30.49
1390.182	609.8180	30.49
3475.455	1524.545	30.49
4865.637	2134.363	30.49
6950.910	3049.090	30.49
8341.092	3658.908	30.49
10426.37	4573.635	30.49
11816.55	5183.453	30.49
13901.82	6098.180	30.49
15292.00	6707.998	30.49
17377.28	7622.725	30.49
CASE 8: (conclusion)		
354.6822	145.3178	29.06
709.3644	290.6356	29.06
1418.729	581.2712	29.06
3546.822	1453.178	29.06
4965.551	2034.449	29.06
7093.644	2906.356	29.06
8512.373	3487.627	29.06
10640.47	4359.534	29.06
12059.19	4940.806	29.06
14187.29	5812.712	29.06
15606.02	6393.984	29.06
17734.11	7265.891	29.06

APPENDIX A

CALCULATIONS OF THE PARAMETERS FOR CYLINDRICAL BUOYS

Part A.2
Triple Buoy Assembly, with Fairing

Internal Buoy Configurations, including:
Flat End Plates
Hemispherical End Bells
Elliptical End Bells (2 cases)
Torospherical End Bells (1 case)
Dished and Flanged End Bells (1 case)

Calculation Expressions for Tricylinder Buoy with Flat Plate End Bells

SuperCalc ver. 2.1

COL	SYMB	EXPRESSION	DESCRIPTION	UNITS	EQUATION
A	Dg	= 200	Buoy Gross Displacement	lb	assigned
B	V_t	= A11/64.3	Volume Displaced	cu ft	D_g / 64.3
C	V_i	= B11/3	Individual Float Volume	cu ft	V_t / 3
D	d_i	= (4*C11/2.154/PI)^(1/3)	Individual Float Diameter	ft	$(4\ V_i\ /\ \pi)^{1/3}$
E	D_f	= D11*2.154	Fairing Diameter	ft	2.154 d_i
F	L_f	= E11	Fairing Length	ft	D_f
G	A_{sf}	= PI*E11*F11	Fairing Surface Area	sq ft	$\pi\ D_f\ L_f$
H	A_{ff}	= E11*F11	Fairing Frontal Area	sq ft	$L_f\ D_f$
I	d	= 2000	Working Depth	ft	assigned
J	S_a	= 24	Allowable Material Stress	psi	assigned
K	t_w	= I11*.446*D11*12/4/J11/1000	Cylinder Wall Thickness	in	$12\ P\ R\ /\ (S_a + 0.4\ P)$ where $P = .446\ d$
L	T_e	= I11*.446*(12*D11/2)^.5*Pi*(1/.27+1)/8/J11/1000/.27	End Bung Thickness	in	$(3\ P\ A_e\ (m + 1)\ /\ 8\ \pi\ m\ S_a)^{1/2}$
M	W_{fe}	= (D11^2/4*PI*K11*40.8)+(D11*F11*L11*40.8)	Weight of Complete Individual Float	lb	$(40.8\ \pi\ d_i^2\ t_w\ /4) + 40.8\ A_e\ t_e$
N	W_f	= E11*F11*.125*40.8	Weight of Fairing (1/8 plate)	lb	5.1 A_{ff}
O	B	= A11-((M11*3)+N11)	Net Buoyancy of 3 Floats with Fairing	lb	$D_g - (W_{fe} + W_f)$
P	E	= 100-100*((A11-O11)/A11)	Efficiency (buoyancy / displacement)	%	$100 - (100\ ((D_g - B)\ /\ D_g)$

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Spreadsheet to Evaluate the Characteristics of a Tricylinder Buoy Assembly Constructed with Flat End Plates.

Displ water pounds Dg	Volume water displ cu ft Vt	Volume of each sub cyl cu ft Vi	diam of each sub cyl ft di	outer diam assy ft D	length assy ft L	Surface Area assy sq ft As	Frontal Area assy sq ft Af	Service depth ft d	Material allowable stress ksi Sa	Cylinder Wall Thickn's in tw
200	3.110420	1.036807	.8494166	1.829643	1.829643	10.51678	3.35	2000	24	.0947099
500	7.776050	2.592017	1.152836	2.483208	2.483208	19.37207	6.17	2000	24	.1285412
1000	15.55210	5.184033	1.452482	3.128646	3.128646	30.75125	9.79	2000	24	.1619517
1200	18.66252	6.220840	1.543492	3.324683	3.324683	34.72564	11.05	2000	24	.1720994
1600	24.88336	8.294453	1.698833	3.659287	3.659287	42.06711	13.39	2000	24	.1894199
2000	31.10420	10.36807	1.830013	3.941847	3.941847	48.81456	15.54	2000	24	.2040464
2500	38.88025	12.96008	1.971321	4.246226	4.246226	56.64428	18.03	2000	24	.2198023
5000	77.76050	25.92017	2.483709	5.349909	5.349909	89.91719	28.62	2000	24	.2769336
7500	116.6407	38.88025	2.843137	6.124118	6.124118	117.8249	37.50	2000	24	.3170098
10000	155.5210	51.84033	3.129277	6.740464	6.740464	142.7346	45.43	2000	24	.3489144
12500	194.4012	64.80041	3.370912	7.260944	7.260944	165.6289	52.72	2000	24	.3758567
15000	233.2815	77.76050	3.582128	7.715905	7.715905	187.0353	59.54	2000	24	.3994073
17500	272.1617	90.72058	3.771002	8.122738	8.122738	207.2787	65.98	2000	24	.4204667
20000	311.0420	103.6807	3.942642	8.492452	8.492452	226.5771	72.12	2000	24	.4396046
25000	388.8025	129.6008	4.247083	9.148216	9.148216	262.9195	83.69	2000	24	.4735497

Flat End Plates Material thickness flat end in Te	weight w/ flat end cap pounds Wflt	weight fairing 1/8 PL pounds Wf	3-cyl Net Buoyancy pounds B	effic-iency % E
.5834133	39.18306	17.07273	65.37809	32.69
.7918136	97.95765	31.44824	174.6788	34.94
.9976227	195.9153	49.92097	362.3331	36.23
1.060132	235.0984	56.37292	438.3320	36.53
1.166827	313.4645	68.29093	591.3156	36.96
1.256926	391.8306	79.24460	745.2636	37.26
1.353982	489.7882	91.95522	938.6800	37.55
1.705911	979.5765	145.9698	1915.301	38.31
1.952780	1469.365	191.2746	2900.631	38.68
2.149313	1959.153	231.7126	3890.828	38.91
2.315277	2448.941	268.8787	4884.298	39.07
2.460349	2938.729	303.6294	5880.182	39.20
2.590075	3428.518	336.4923	6877.955	39.30
2.707965	3918.306	367.8209	7877.261	39.39
2.917066	4897.882	426.8183	9879.534	39.52

Expressions for Calculation of Parameters of Tricylinder Buoys with Hemispherical End Bells

SuperCalc ver. 2.1

COL	SYMB	EXPRESSION	DESCRIPTION	UNITS	EQUATION
A	Dg	= 200	Buoy Gross Displacement	lb	assigned
B	V_t	= A11/64.3	Volume Displaced	cu ft	$D_g / 64.3$
C	V_i	= B11/3	Individual Float Volume	cu ft	$V_t / 3$
D	d_i	= (4*C11/2.154/PI)^(1/3)	Individual Float Diameter	ft	$(4 V_i / \pi)^{1/3}$
E	D_f	= D11*2.154	Fairing Diameter	ft	$2.154\ d_i$
F	L_f	= E11	Fairing Length	ft	D_f
G	A_s	= PI*E11*F11	Fairing Surface Area	sq ft	$\pi D_f L_f$
H	A_f	= E11*F11	Fairing Frontal Area	sq ft	$L_f D_f$
I	d	= 2000	Working Depth	ft	assigned
J	S_a	= 24	Allowable Material Stress	psi	assigned
K	t_c	= I11*.446*D11*12/4/J11/1000	Cylinder Wall Thickness	in	$12 P R / (S_a + 0.4 P)$
L	I	BEGIN CALCULATION OF END BELLS			
M	V_e	= 4*PI/3*(D11/2)^3	Volume of 2 End Bells	cu ft	$4 \pi (d)^3 / 3$
N	t_e	= I11*.446*D11*6/(J11*1000+(.446*I11))	End Bell Thickness	in	$6 P d_i / (S_a + 0.8 P)$
O	L_c	= (C11-M11)/(PI*(D11/2)^2)	Length of Cylinder Wall	ft	$V_i - V_e / (\pi (d_i /2)^2)$
P	L	= D11+O11	Overall Buoy Length	ft	$d_i + L_c$
Q	A_s	= (4*PI*(D11/2)^2)+(O11*D11*PI)	Float Surface Area	sq ft	$4 \pi (d/2)^2 + \pi d_i L$
R	W_s	= K11*O11*PI*D11*40.8+N11*4*PI*(D11/2)^2*40.8	Whole Float Weight	lb	$40.8\ t_c A_s + 40.8\ t_e 4 \pi (d_i / 2)^2$
S	W	= 3*R11+P11*E11*PI	Assy Weight with Fairing	lb	$3 W_s + \pi D L$
T	B	= A11-S11	Net Buoyancy	lb	$D_g - W$
U	E	= 100-(100*(A11-T11)/A11)	Efficiency	%	$100(100((D_g - B) / D_g))$

8/22/90

Spreadsheet to Evaluate the Characteristics of a Tricylinder Buoy Assembly with Hemispherical End Bells

Displ water pounds Dg	Volume water displ cu ft Vt	Volume of each sub cyl cu ft Vi	diam of each sub cyl ft di	outer diam assy ft D	length assy ft L	Surface Area assy sq ft As	Frontal Area assy sq ft Af	Service depth ft d	Material allowable stress ksi Sa	Cylinder Wall Thickness in tw
200	3.110420	1.036807	.8494166	1.829643	1.829643	10.51678	3.35	2000	24	.0947099
500	7.776050	2.592017	1.152836	2.483208	2.483208	19.37207	6.17	2000	24	.1285412
1000	15.55210	5.184033	1.452482	3.128646	3.128646	30.75125	9.79	2000	24	.1619517
1200	18.66252	6.220840	1.543492	3.324683	3.324683	34.72564	11.05	2000	24	.1720994
1600	24.88336	8.294453	1.698833	3.659287	3.659287	42.06711	13.39	2000	24	.1894199
2000	31.10420	10.36807	1.830013	3.941847	3.941847	48.81456	15.54	2000	24	.2040464
2500	38.88025	12.96008	1.971321	4.246226	4.246226	56.64428	18.03	2000	24	.2198023
5000	77.76050	25.92017	2.483709	5.349909	5.349909	89.91719	28.62	2000	24	.2769336
7500	116.6407	38.88025	2.843137	6.124118	6.124118	117.8249	37.50	2000	24	.3170098
10000	155.5210	51.84033	3.129277	6.740464	6.740464	142.7346	45.43	2000	24	.3489144
12500	194.4012	64.80041	3.370912	7.260944	7.260944	165.6289	52.72	2000	24	.3758567
15000	233.2815	77.76050	3.582128	7.715905	7.715905	187.0353	59.54	2000	24	.3994073
17500	272.1617	90.72058	3.771002	8.122738	8.122738	207.2787	65.98	2000	24	.4204667
20000	311.0420	103.6807	3.942642	8.492452	8.492452	226.5771	72.12	2000	24	.4396046
25000	388.8025	129.6008	4.247083	9.148216	9.148216	262.9195	83.69	2000	24	.4735497

Hemispherical end bells (continued)

Heads volume cu ft Ve	Material thick hem sphr in te	cylinder wall length ft Lc	Subbuoy length w/hemis ft L	Subbuoy surface area sq ft As	Subbuoy weight pounds Ws	Total Weight w/fair´g pounds W	Net Buoyancy pounds B	effic-iency % E
.3208934	.1826321	1.263366	2.112782	5.638003	29.91729	101.8961	98.10388	49.05
.8022335	.2478699	1.714651	2.867487	10.38529	74.79322	246.7496	253.2504	50.65
1.604467	.3122964	2.160325	3.612807	16.48562	149.5864	484.2693	515.7307	51.57
1.925361	.3318645	2.295688	3.839180	18.61628	179.5037	578.6106	621.3894	51.78
2.567147	.3652641	2.526731	4.225564	22.55201	239.3383	766.5919	833.4081	52.09
3.208934	.3934689	2.721839	4.551851	26.16929	299.1729	953.8872	1046.113	52.31
4.011168	.4238515	2.932012	4.903333	30.36677	373.9661	1187.308	1312.692	52.51
8.022335	.5340194	3.694103	6.177812	48.20425	747.9322	2347.628	2652.372	53.05
12.03350	.6112996	4.228693	7.071830	63.16544	1121.898	3501.753	3998.247	53.31
16.04467	.6728223	4.654279	7.783556	76.51948	1495.864	4652.416	5347.584	53.48
20.05584	.7247759	5.013670	8.384582	88.79299	1869.830	5800.751	6699.249	53.59
24.06701	.7701893	5.327819	8.909947	100.2689	2243.796	6947.369	8052.631	53.68
28.07817	.8107987	5.608737	9.379739	111.1213	2617.763	8092.643	9407.357	53.76
32.08934	.8477030	5.864024	9.806666	121.4671	2991.729	9236.826	10763.17	53.82
40.11168	.9131604	6.316828	10.56391	140.9501	3739.661	11522.59	13477.41	53.91

Spreadsheet Calculation Expressions for Tricylinder Buoy with Elliptical End Bells

SuperCalc ver. 2.1

COL	SYMBOL	EXPRESSION	DESCRIPTION	UNITS	EQUATION
A	D_g	= 200	Gross Water Displacement	lb	assigned
B	V_b	= A11/64.3	Volume Displaced	cu ft	D_g / 64.3
C	V_i	= B11/3	Individual Float Volume	cu ft	V_b / 3
D	d_i	= (4*C11/2.154/PI)^(1/3)	Individual Float Diameter	ft	$(4\ V_b\ /\pi)^{1/3}$
E	D_f	= D11*2.154	Fairing Diameter	ft	2.154 d_i
F	L_f	= E11	Fairing Length (ref)	ft	D_f
G	A_w	= PI*E11*F11	Fairing Surface Area	sq ft	$\pi\ D_f\ L_f$
H	A_f	= E11*F11	Fairing Frontal Area	sq ft	$D_f\ L_f$
I	d	= 2000	Working Water Depth	ft	assigned
J	S_a	= 24	Material Allowable Stress	ksi	assigned
K	t_c	= I11*.446*D11*12/4/J11/1000	Cylinder Wall Thickness	in	$12\ P\ d_i\ /\ (4\ S_a\ )$ {P = .446 d}
L	|		BEGIN CALCULATION OF 2:1 END BELL ASSEMBLY		
M	V_e	= 4*PI/3*(D11/2)^3/2	Volume of Elliptical End Bells	cu ft	$4\ \pi\ (d/2)^3\ /6$
N	t_e	= I11*.446*E11*12/((2*J11*1000)+(1.8*I11*.446))	End Bell Thickness	in	$12\ P\ d_i\ /\ (2\ S_a\ +\ (1.8\ P))$
O	L_c	= (C11-M11)/PI/(D11/2)^2	Length of Actual Cylindrical Section	ft	$V_i\ -\ V_e\ /\ (\pi\ (d/2)^2$
P	L_b	= O11+D11/2	Total Length of Buoy	ft	$L_c\ +\ d/2$
Q	e	= ((D11/2)^2-(D11/2/2)^2)^.5/D11*2	Eccentricity Factor of Ellipse	-	$((d/2)^2\ -\ (d/4)^2)^{1/2}\ /\ (d/2)$
R	A_e	= 2*PI*(D11/2)^2+PI*(D11/2/2)^2/Q11*LN((1+Q11)/(1-Q11))	End Bells Surface Area	sq ft	$2\ \pi\ (d/2)^2\ +\ \pi\ ((d/4)^2/e)\ \ln[(1+e)\ /\ (1-e)]$
S	W_b	= R11*N11*40.8+(PI*D11/2^2*K11*40.8)	Complete 1-Buoy Weight	lb	$40.8\ ((S_{ae}\ t_e)\ +\ (\pi\ (d/2)^2\ t_w))$
T	B	= A11-(3*S11+(2.154*D11*P11*5.1))	Net Buoyancy	lb	$D_g\ -\ (3\ W_b\ +\ (5.1\ \pi\ 2.154\ d_i\ L_b))$
U	E	= 100-100*((A11-T11)/A11)	Efficiency	%	$100\ -\ (100\ (D_g\ -\ B)\ /\ D_g)$
V	|		BEGIN CALCULATION OF 1.8:1 ASSEMBLY		
W	V_e	= 4*PI/3*(D11/1.8)^3/1.8	Volume of End Bells	cu ft	$4\ \pi\ (d/\ 1.8)^3\ /\ 5.4$
X	t_e	= I11*.446*D11*12/((2*J11*1000)+(1.8*I11*.446))	Thickness of End Bells	in	$12\ P\ d_i\ /\ (2\ S_a\ +\ (1.8\ P))$
Y	L_c	= (C11-W11)/PI/(D11/2)^2	Length of Cylindrical Section	ft	$V_i\ -\ V_e\ /\ (\pi\ (d_i\ /\ 2)^2)$
Z	L_i	= Y11+D11/2	Total Length of Individual Buoy	ft	$L_c\ +\ (d_i\ /\ 2)$
AA	e	= ((D11/2)^2-(D11/2/1.8)^2)^.5/D11*2	End Bell Eccentricity Factor	-	$((d_i\ /\ 2)^2\ -\ (d_i\ /\ 3.6)^2\ )^{1/2}\ /\ (d_i\ /\ 2)$
AB	A_e	= 2*PI*(D11/2)^2+PI*(D11/2/1.8)^2/AA11*LN((1+AA11)/(1-AA11))	End Bells Surface Area	sq ft	$2\ \pi\ (d_i\ /\ 2)^2\ +\ \pi\ (d_i\ /\ 1.8)^2\ \ln[(1\ +\ e)\ /\ (1\ -\ e)]\ /\ e$
AC	W_b	= AB11*X11*40.8+D11*Y11*K11*40.8	Total Buoy Weight	lb	$40.8\ (A_e\ t_e\ +\ \pi\ d_i\ L_c\ t_w)$
AD	B	= A11-(3*AC11+(PI*E11*Z11*5.1))	Net Buoyancy	lb	$D_g\ -\ (3\ W_b\ +\ 5.1\ \pi\ D\ L_i)$
AE	E	= 100-100*((A11-AD11)/A11)	Efficiency	%	$100\ -\ (100\ (D_g\ -\ B)\ /\ D_g)$

9/4/90

Spreadsheet to Evaluate the Characteristics of a Tricylinder Buoy Assembly For Cylindrical Buoys with Elliptical End Bells

Displ water pounds Dg	Volume water displ cu ft Vt	Volume of each sub cyl cu ft Vi	diam of each sub cyl ft di	outer diam assy ft D	length assy ft L	Surface Area assy sq ft As	Frontal Area assy sq ft Af	Service depth ft d	Material allowable stress ksi Sa	Cylinder Wall Thickn's in tw
200	3.110420	1.036807	.8494166	1.829643	1.829643	10.51678	3.35	2000	24	.0947099
500	7.776050	2.592017	1.152836	2.483208	2.483208	19.37207	6.17	2000	24	.1285412
1000	15.55210	5.184033	1.452482	3.128646	3.128646	30.75125	9.79	2000	24	.1619517
1200	18.66252	6.220840	1.543492	3.324683	3.324683	34.72564	11.05	2000	24	.1720994
1600	24.88336	8.294453	1.698833	3.659287	3.659287	42.06711	13.39	2000	24	.1894199
2000	31.10420	10.36807	1.830013	3.941847	3.941847	48.81456	15.54	2000	24	.2040464
2500	38.88025	12.96008	1.971321	4.246226	4.246226	56.64428	18.03	2000	24	.2198023
5000	77.76050	25.92017	2.483709	5.349909	5.349909	89.91719	28.62	2000	24	.2769336
7500	116.6407	38.88025	2.843137	6.124118	6.124118	117.8249	37.50	2000	24	.3170098
10000	155.5210	51.84033	3.129277	6.740464	6.740464	142.7346	45.43	2000	24	.3489144
12500	194.4012	64.80041	3.370912	7.260944	7.260944	165.6289	52.72	2000	24	.3758567
15000	233.2815	77.76050	3.582128	7.715905	7.715905	187.0353	59.54	2000	24	.3994073
17500	272.1617	90.72058	3.771002	8.122738	8.122738	207.2787	65.98	2000	24	.4204667
20000	311.0420	103.6807	3.942642	8.492452	8.492452	226.5771	72.12	2000	24	.4396046
25000	388.8025	129.6008	4.247083	9.148216	9.148216	262.9195	83.69	2000	24	.4735497

2 to 1 Semi-elliptical heads

Heads Volume cu ft Ve	Material thick ellipse in te	Cylinder wall length Lcyl	Sub Buoy length w/ellip ft Lb	ellipse eccen-tricity e	Sub Buoy surface area sq ft As	weight w/ends pounds Wb	Net Buoyancy pounds	effic-iency % E
.1604467	.3948043	1.546504	1.971213	.8660254	1.564209	392.4203	**-995.655**	**-497.83**
.4011168	.5358318	2.098929	2.675347	.8660254	2.881298	561.3904	**-1218.05**	**-243.61**
.8022335	.6751058	2.644485	3.370726	.8660254	4.573776	753.9257	**-1315.56**	**-131.56**
.9626803	.7174069	2.810185	3.581931	.8660254	5.164905	818.4680	**-1316.14**	**-109.68**
1.283574	.7896085	3.093009	3.942425	.8660254	6.256837	936.0184	**-1281.63**	**-80.10**
1.604467	.8505800	3.331843	4.246849	.8660254	7.260416	1043.123	**-1214.75**	**-60.74**
2.005584	.9162595	3.589119	4.574779	.8660254	8.424967	1167.205	**-1100.69**	**-44.03**
4.011168	1.154415	4.522006	5.763861	.8660254	13.37380	1703.677	**-268.295**	**-5.37**
6.016752	1.321475	5.176405	6.597974	.8660254	17.52464	2174.021	771.8639	10.29
8.022335	1.454471	5.697371	7.262010	.8660254	21.22959	2612.680	1912.319	19.12
10.02792	1.566782	6.137307	7.822763	.8660254	24.63475	3032.098	3114.022	24.91
12.03350	1.664954	6.521862	8.312926	.8660254	27.81863	3438.366	4357.778	29.05
14.03909	1.752741	6.865737	8.751238	.8660254	30.82953	3834.975	5632.547	32.19
16.04467	1.832519	7.178238	9.149559	.8660254	33.69987	4224.133	6931.320	34.66
20.05584	1.974021	7.732522	9.856064	.8660254	39.10523	4985.658	9583.183	38.33

1.8:1 Semi-Elliptical Head

Volume 2 heads cu ft Ve	Head thickn's in te	Length cylinder wall ft Lc	Length wall + ends ft Lt	head eccen-tricity e	Heads Surface area sq ft As	Weight 3 sub buoys pounds Wb	Net Buoyancy pounds B	effic-iency % E
.2445461	.1832889	1.398095	1.822803	.8314794	1.635192	16.81722	132.5394	66.27
.6113653	.2487613	1.897507	2.473925	.8314794	3.012049	30.57067	376.9573	75.39
.8913706	.3134196	2.590690	3.316931	.8314794	4.781329	61.14134	763.6507	76.37
1.069645	.3330580	2.753019	3.524765	.8314794	5.399284	73.36960	920.1257	76.68
1.426193	.3665778	3.030089	3.879506	.8314794	6.540766	97.82614	1234.121	77.13
1.782741	.3948839	3.264065	4.179071	.8314794	7.589887	122.2827	1549.138	77.46
2.228427	.4253758	3.516107	4.501768	.8314794	8.807284	152.8533	1943.951	77.76
4.456853	.5359399	4.430017	5.671872	.8314794	13.98069	305.7067	3928.126	78.56
6.685280	.6134981	5.071104	6.492672	.8314794	18.31989	458.5600	5921.534	78.95
8.913706	.6752420	5.581472	7.146111	.8314794	22.19296	611.4134	7920.103	79.20
11.14213	.7273824	6.012458	7.697914	.8314794	25.75265	764.2667	9922.140	79.38
13.37056	.7729592	6.389190	8.180255	.8314794	29.08101	917.1201	11926.74	79.51
15.59899	.8137147	6.726071	8.611572	.8314794	32.22854	1069.973	13933.34	79.62
17.82741	.8507516	7.032214	9.003535	.8314794	35.22913	1222.827	15941.56	79.71
22.28427	.9164444	7.575223	9.698764	.8314794	40.87979	1528.533	19961.90	79.85

Spreadsheet Calculations for Tricylinder Buoy Assembly and Fairing Utilizing Torospherical End Bells in the Float Construction. Values for End Bell Height and for Flange Radius Are Assigned as a Ratio to the Buoy Radius.

SuperCalc ver. 2.1

COL.	SYMB	EXPRESSION	DESCRIPTION	UNITS	EQUATION
A	D_g	= 200	Buoy Gross Displacement	pounds	assigned
B	V_t	= A11/64.3	Total Volume	cu ft	$D_g/64.3$
C	V_i	= B11/3	Individual Float Volume	cu ft	$V_t/3$
D	d_i	= (4*C11/2.154/PI)^(1/3)	Individual Float Diameter	ft	$(4V_i/(2.154\ \pi))^{1/3}$
E	D	= D11*2.154	Outer Fairing Diameter	ft	$2.154\ d_i$
F	L	= E11	Fairing Length (basic)	ft	D
G	A_s	= π*E11*F11	Fairing Surface Area	sq ft	π D L
H	A_f	= E11*F11	Fairing Frontal Area	sq ft	D L
I	d	= 2000	Working Depth of Buoy	ft	assigned
J	S_a	= 24	Allowable Material Stress	ksi	assigned
K	t_c	= I11*.446*D11*12/4/J11/1000	Float cyl wall thickness	in	$12\ P\ d_i\ /\ (4\ S_a)$
L		= |	CALCULATE END BELL PARAMETERS		
M	a	= 2	Height Aspect Ratio		assigned
N	f	= 5	Flange to Buoy Radius Ratio		assigned
O	W	= D11/2	End Bell Major semi-axis	ft	$d_i\ /\ 2$
P	H	= O11/M11	End Bell Minor semi-axis	ft	W / a
Q	r	= O11/N11	End Bell Flange radius	ft	W / f
R	j	= P11-Q11	calc parameter	ft	H - r
S	w	= O11-Q11	calc parameter	ft	W - r
T	ψ	= ATAN(R11/S11)	calc parameter	ft	atan(j / w)
U	ϕ	= 2*T11	Crown half angle	radians	$2\ \psi$
V	ϕ(d)	= U11/PI*180	" " "	degrees	$\psi(r)\ 180/\pi$
W	θ	= (PI/2)-U11	Flange Arc	radians	$(\pi\ /\ 2) - \psi(r)$
X	θ(d)	= W11*180/PI	" " "	degrees	$\theta(r)\ 180\ /\ \pi$
Y	C	= P11-Q11*SIN(W11)	Crown Height	ft	$H - r \sin\theta$
Z	R_c	= Q11+S11/SIN(U11)	Crown Radius	ft	$r + w\ /\ \sin\phi$
AA	V_c	= PI/3*Y11^2*(3*Z11-Y11)	Crown Volume	cu ft	$C^2\ \pi\ (3\ R_c - C)\ /\ 3$
AB	V_f	= PI*(O11^2*Q11*SIN(W11)-((Q11*SIN(W11))^3)/3)	Flange Disc Volume	cu ft	$\pi\ ((W^2\ r \sin\theta) - (1/3\ ((r \sin\theta)^3))$
AC	V_e	= AA11+AB11	End Bell Volume	cu ft	$V_c + V_f$
AD	V_b	= 2*AC11	Both End Bells Volume	cu ft	$2\ V_e$
AE	l_1	= 2*PI*Z11*V11/360	area calc parameter	ft	$2\ \pi\ R_c\ \phi/360$
AF	c_1	= 2*Z11*SIN(U11/2)	"	ft	$2\ R_c \sin(\phi/2)$
AG	d_1	= Z11*AF11/AE11	"	ft	$R_c\ c_1\ /\ l_1$
AH	s_1	= AG11*SIN(U11/2)	"	ft	$d_1 \sin(\phi/2)$
AI	l_2	= 2*PI*Q11*X11/360	"	ft	$2\ \pi\ r\ \theta/360$
AJ	c_2	= 2*Q11*SIN(W11/2)	"	ft	$r \sin(\theta/2)$
AK	d_2	= Q11*AJ11/AI11	"	ft	$r\ c_2\ /\ l_2$
AL	s_2	= AK11*COS(W11/2)+S11	"	ft	$d_2 \cos(\theta/2) + w$
AM	X	= ((AE11*AH11)+(AI11*AL11))/(AE11+AI11)	Bell Outline CG radius	ft	$((l_1\ s_1) + (l_2\ s_2))\ /\ (l_1 + l_2)$
AN	A_e	= 4*AM11*(AE11+AI11)	Bell Surface Area	sq ft	$4\ X\ (l_1 + l_2)$
AO	A_b	= 2*AN11	2 Bells Surface Area	sq ft	$2\ A_e$
AP	M	= (3+(Z11/Q11)^.5)/4	Knuckle Stress Correction Factor		$(3 + R_c\ /\ r)^{1/2}\ /4$
AQ	t_e	= I11*.446*Z11*AP11*12/(2*J11*1000+(I11*.446*(AP11-.02)))	End Bell Thickness	in	$P\ R_c\ M\ /\ (2\ S_a\ P\ (M-.02))$ where P = .446 d
AR	W_e	= AO11*AQ11*40.8	Weight End Bells	lb	$40.8\ A_b\ t_e$
AS	V_c	= C11-AD11	Volume Cylindrical Section	cu ft	$V_i - V_b$
AT	L_c	= 4*AS11/PI/D11^2	Length Cylindrical Section	ft	$4\ V_c\ /\ (\pi\ d_i^2)$
AU	L_b	= AT11+2*P11	Total Buoy Length	ft	$L_c + 2\ H$
AV	A_{sb}	= AO11+(PI*D11*AU11)	Total Buoy Surface Area	sq ft	$A_b + \pi\ d_i\ L_b$
AW	W_c	= 40.8*PI*D11*AT11*K11	Weight Cylindrical Section	lb	$40.8\ \pi\ d_i\ L_c\ t_c$
AX	W_b	= AR11+AW11	Weight one Buoy of three	lb	$W_e + W_c$
AY	A_b	= PI*Z11^2*V11/360-(S11*P11)+(π*Q11^2*X11/360)	End Bell Frontal Area	sq ft	$Pi\ R_c^2\ \phi/360 - w\ H + (\pi\ r^2\ \theta/360)$
AZ	B_f	= A11/3-AX11	Buoyancy one Float of three	lb	$D_g - W_b$
BA	E	= 100-(((A11/3-AZ11)/A11*3)*100)	Efficiency of one Float	%	$100 - 100((D_g/3 - B_f)\ /\ (D_g/3))$
BB	A_{sf}	= PI*E11*AU11+2*PI*E11^2/4	Fairing Surface Area	sq ft	$\pi\ D\ L_b + 2\ \pi\ D^2\ /4$
BC	W_f	= 5.1*BB11	Weight 1/8 Plate Fairing	lb	$5.1\ A_{sf}$
BD	A_f	= D11^2	Fairing Frontal Area	sq ft	D^2
BE	W_f	= .869*BC11	Fairing Wet Weight	lb	$.869\ W_f$
BF	W_w	= 3*AX11+BE11	Weight Faired 3-Float Assy	lb	$3\ W_b + W_f$
BG	B_w	= A11-BF11	Assembly Net Buoyancy	lb	$D_g - W_w$
BH	E	= 100-(((A11-BG11)/A11)*100)	Efficiency of Complete Assembly	%	$100-100((D_g - B_w)\ /\ D_g)$

Expressions for Torospherical End Bells in a Tricylinder Buoy

8/22/90

Spreadsheet to Evaluate the Characteristics of a Tricylinder Buoy Assembly Using Torospherical End Bells

Displ water pounds Dg	Volume water displ cu ft Vt	Volume of each sub cyl cu ft Vi	diam of each sub cyl ft di	outer diam assy ft D	length assy ft L	Surface Area assy sq ft As	Frontal Area assy sq ft Af	Service depth ft d	Material allowable stress ksi Sa	Cylinder Wall Thickn's in tw
200	3.110420	1.036807	.8494166	1.829643	1.829643	10.51678	3.35	2000	24	.0947099
500	7.776050	2.592017	1.152836	2.483208	2.483208	19.37207	6.17	2000	24	.1285412
1000	15.55210	5.184033	1.452482	3.128646	3.128646	30.75125	9.79	2000	24	.1619517
1200	18.66252	6.220840	1.543492	3.324683	3.324683	34.72564	11.05	2000	24	.1720994
1600	24.88336	8.294453	1.698833	3.659287	3.659287	42.06711	13.39	2000	24	.1894199
2000	31.10420	10.36807	1.830013	3.941847	3.941847	48.81456	15.54	2000	24	.2040464
2500	38.88025	12.96008	1.971321	4.246226	4.246226	56.64428	18.03	2000	24	.2198023
5000	77.76050	25.92017	2.483709	5.349909	5.349909	89.91719	28.62	2000	24	.2769336
7500	116.6407	38.88025	2.843137	6.124118	6.124118	117.8249	37.50	2000	24	.3170098
10000	155.5210	51.84033	3.129277	6.740464	6.740464	142.7346	45.43	2000	24	.3489144
12500	194.4012	64.80041	3.370912	7.260944	7.260944	165.6289	52.72	2000	24	.3758567
15000	233.2815	77.76050	3.582128	7.715905	7.715905	187.0353	59.54	2000	24	.3994073
17500	272.1617	90.72058	3.771002	8.122738	8.122738	207.2787	65.98	2000	24	.4204667
20000	311.0420	103.6807	3.942642	8.492452	8.492452	226.5771	72.12	2000	24	.4396046
25000	388.8025	129.6008	4.247083	9.148216	9.148216	262.9195	83.69	2000	24	.4735497

Section for Toro-spherical heads with a (height:diameter ratio) and f (flange radius:diameter ratio) assigned

aspect ratio H to W a	flange to Diameter ratio f	Bell radius ft W	Bell height ft H	flange radius ft r	param j	param w	param psi	Crown half angle rad phi	Crown half angle deg phi	flange arc angle rad theta	flange arc angle deg theta
2	5	.4247083	.2123541	.0849417	.1274125	.3397666	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	.5764178	.2882089	.1152836	.1729253	.4611343	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	.7262410	.3631205	.1452482	.2178723	.5809928	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	.7717462	.3858731	.1543492	.2315239	.6173969	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	.8494166	.4247083	.1698833	.2548250	.6795333	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	.9150063	.4575031	.1830013	.2745019	.7320050	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	.9856606	.4928303	.1971321	.2956982	.7885285	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	1.241855	.6209273	.2483709	.3725564	.9934836	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	1.421569	.7107843	.2843137	.4264706	1.137255	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	1.564639	.7823194	.3129277	.4693916	1.251711	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	1.685456	.8427280	.3370912	.5056368	1.348365	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	1.791064	.8955321	.3582128	.5373193	1.432851	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	1.885501	.9427505	.3771002	.5656503	1.508401	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	1.971321	.9856606	.3942642	.5913964	1.577057	.3587707	.7175413	41.11209	.8532550	48.88791
2	5	2.123541	1.061771	.4247083	.6370624	1.698833	.3587707	.7175413	41.11209	.8532550	48.88791

crown height ft C	crown radius ft Rc	crown volume cu ft Vc	flange disk volume cu ft Vf	Bell volume cu ft Ve	2 ends volume cu ft Vb	- -- - - - - -- - - - -- - -area calc parameters - - - l1	c1	d1	s1	l2	c2
.1483570	.6016701	.0381836	.0359909	.0741744	.1483488	.4317231	.4225209	.5888454	.2067574	.0724769	.0702982
.2013514	.8165919	.0954589	.0899772	.1854361	.3708721	.5859385	.5734491	.7991862	.2806130	.0983663	.0954094
.2536869	1.028841	.1909178	.1799544	.3708721	.7417442	.7382362	.7225006	1.006912	.3535502	.1239337	.1202083
.2695826	1.093307	.2291013	.2159452	.4450465	.8900931	.7844930	.7677715	1.070003	.3757032	.1316993	.1277403
.2967140	1.203340	.3054684	.2879270	.5933954	1.186791	.8634463	.8450419	1.177691	.4135149	.1449538	.1405964
.3196255	1.296259	.3818355	.3599087	.7417442	1.483488	.9301193	.9102938	1.268629	.4454454	.1561467	.1514529
.3443061	1.396353	.4772944	.4498859	.9271803	1.854361	1.001941	.9805842	1.366589	.4798415	.1682040	.1631477
.4337985	1.759294	.9545888	.8997718	1.854361	3.708721	1.262366	1.235459	1.721794	.6045624	.2119237	.2055532
.4965753	2.013889	1.431883	1.349658	2.781541	5.563082	1.445049	1.414247	1.970963	.6920512	.2425921	.2352997
.5465519	2.216571	1.909178	1.799544	3.708721	7.417442	1.590482	1.556580	2.169325	.7617009	.2670072	.2589808
.5887552	2.387729	2.386472	2.249430	4.635902	3.271803	1.713294	1.676775	2.336835	.8205174	.2876247	.2789787
.6256457	2.537341	2.863766	2.699315	5.563082	11.12616	1.820647	1.781840	2.483257	.8719299	.3056469	.2964591
.6586339	2.671126	3.341061	3.149201	6.490262	12.98052	1.916644	1.875790	2.614191	.9179037	.3217626	.3120903
.6886122	2.792705	3.818355	3.599087	7.417442	14.83488	2.003881	1.961168	2.733178	.9596830	.3364079	.3262954
.7417850	3.008350	4.772944	4.498859	9.271803	18.54361	2.158616	2.112605	2.944227	1.033787	.3623845	.3514911

Expressions for Torospherical End Bells in a Tricylinder Buoy

8/22/90

Spreadsheet to Evaluate the Characteristics of a Tricylinder Buoy Assembly Using Torospherical End Bells

- - - - -	- - - - -	CG rotation radius ft	Bell Surface Area sq ft	2 bells Surface Area sq ft	1/nu	Thickn's end bells in	Weight end bells lb	Volume Cyl sect cu ft	Length Cyl body ft
d2	s2	X	As	Ab	M	te	We	Vc	Lc
.0823883	.4147702	.2366585	.4772929	.9545858	1.415363	.1851029	7.209222	.8884578	1.567853
.1118181	.5629297	.3211950	.8791810	1.758362	1.415363	.2512233	18.02305	2.221144	2.127904
.1408820	.7092470	.4046803	1.395613	2.791226	1.415363	.3165215	36.04611	4.442289	2.680992
.1497095	.7536874	.4300370	1.575960	3.151973	1.415363	.3363543	43.25533	5.330747	2.848979
.1647766	.8295403	.4733170	1.909172	3.818343	1.415363	.3702058	57.67377	7.107662	3.135707
.1775002	.8935952	.5098653	2.215397	4.430795	1 415363	.3987921	72.09222	8.884578	3.377838
.1912063	.9625963	.5492357	2.570741	5.141482	1.415363	.4295858	90.11527	11.10572	3.638665
.2409048	1.212795	.6919936	4.080797	8.161594	1.415363	.5412442	180.2305	22.21144	4.584431
.2757672	1.388304	.7921350	5.347357	10.69471	1.415363	.6195700	270.3458	33.31717	5.247864
.3035210	1.528026	.8718573	6.477861	12.95572	1.415363	.6819250	360.4611	44.42289	5.776021
.3269581	1.646016	.9391798	7.516892	15.03378	1.415363	.7345814	450.5764	55.52861	6.222030
.3474449	1.749154	.9980275	8.488399	16.97680	1.415363	.7806092	540.6916	66.63433	6.611894
.3657644	1.841380	1.050650	9.407127	18.81425	1.415363	.8217681	630.8069	77.74006	6.960517
.3824125	1.925193	1.098471	10.28296	20.56593	1.415363	.8591716	720.9222	88.84578	7.277331
.4119414	2.073851	1.183292	11.93232	23.86464	1.415363	.9255146	901.1527	111.0572	7.839267

Whole Buoy Length ft	Sub buoy Surface Area sq ft	Cyl Weight lb	Whole buoy Weight lb	Frontal Area end bell sq ft	Net Buoync'y sub buoy lb	Effic-iency Buoy %
Lb	Asb	Wc	Wb	Afb	Bf	E
1.992562	6.271778	16.16709	23.37631	.0608048	43.29036	64.94
2.704322	11.55271	40.41772	58.44078	.1120033	108.2259	64.94
3.407233	18.33879	80.83544	116.8816	.1777942	216.4518	64.94
3.620725	20.70896	97.00253	140.2579	.2007729	259.7421	64.94
3.985123	25.08711	129.3367	187.0105	.2432190	346.3229	64.94
4.292844	29.11102	161.6709	233.7631	.2822307	432.9036	64.94
4.624326	33.78034	202.0886	292.2039	.3274997	541.1295	64.94
5.826286	53.62295	404.1772	584.4078	.5198733	1082.259	64.94
6.669432	70.26594	606.2658	876.6116	.6812268	1623.388	64.94
7.340660	85.12113	808.3544	1168.816	.8252474	2164.518	64.94
7.907486	98.77432	1010.443	1461.019	.9576148	2705.647	64.94
8.402958	111.5402	1212.532	1753.223	1.081380	3246.777	64.94
8.846018	123.6126	1414.620	2045.427	1.198421	3787.906	64.94
9.248652	135.1214	1616.709	2337.631	1.309999	4329.036	64.94
9.962809	156.7945	2020.886	2922.039	1.520119	5411.295	64.94

Summary Data for Triple Buoy Assembly with a Fairing of 1/8 in Plate

Surface Area Fairing sq ft	Fairing weight (1/8 pl) lb	Surface Area Fairing sq ft	Wet Fairing Weight lb	3 Buoys with Fairing lb	Net Buoyancy Assy lb	Effic-iency Assy %
Asfrg	Wf	Aff	Wf	WN	Bw	E
16.71162	85.22927	.7215085	74.06424	144.1932	55.80683	27.90
30.78307	156.9937	1.329030	136.4275	311.7498	188.2502	37.65
48.86508	249.2119	2.109704	216.5651	567.2098	432.7902	43.28
55.18056	281.4209	2.382369	244.5547	665.3283	534.6717	44.56
66.84649	340.9171	2.886034	296.2569	857.2884	742.7116	46.42
77.56848	395.5992	3.348946	343.7757	1045.065	954.9350	47.75
90.01024	459.0522	3.886107	398.9164	1275.528	1224.472	48.98
142.9824	728.7000	6.168811	633.2403	2386.464	2613.536	52.27
187.2289	954.8672	8.083429	829.7796	3459.614	4040.386	53.87
226.8116	1156.739	9.792377	1005.206	4511.653	5488.347	54.88
263.1916	1342.277	11.36305	1166.439	5549.497	6950.503	55.60
297.2073	1515.757	12.83164	1317.193	6576.863	8423.137	56.15
329.3750	1679.813	14.22046	1459.757	7596.039	9903.961	56.59
360.0410	1836.209	15.54443	1595.666	8608.559	11391.44	56.96
417.7905	2130.732	18.03771	1851.606	10617.72	14382.78	57.53

Spreadsheet Expressions and Equations to Compute the Parameters for Tricylinder Buoys Using Dished and Flanged End Bells.

SuperCalc ver. 2.1

COL	SYMB	EXPRESSION	DESCRIPTION	UNITS	EQUATION
A	D_g	= 200	Buoy Gross Displacement	pounds	assigned
B	V_t	= A11/64.3	Total Buoy Volume	cu ft	$D_g / 64.3$
C	V_i	= B11/3	Individual Float Volume	cu ft	$V_t / 3$
D	d_i	= (4*C11/2.154/PI)^(1/3)	Individual Float Diameter	ft	$(4\ V_i /(2.54\ \pi))^{1/3}$
E	D_f	= D11*2.154	Outer Fairing Diameter	ft	$2.154\ d_i$
F	L_f	= E11	Buoy Length (ref flat end)	ft	D_f
G	A_{sf}	= PI*E11*F11	Fairing Surface Area	sq ft	$\pi\ D_f\ L_f$
H	A_{fr}	= E11*F11	Fairing Frontal Area	sq ft	$D_f\ L_f$
I	d	= 2000	Working Depth	ft	assigned
J	S_a	= 24	Material Allowable Stress	ksi	assigned
K	t_c	= I11*.446*D11*12/4/J11/1000	Cylinder Wall Thickness	in	$12\ P\ A_s / (4\ S_a)$
L	t_{fe}	= I11*.446*D11*12*1.54/J11/1000	Thickness of Flat End Plate	in	not applicable
M	R	= D11	Crown Radius	ft	d_i
N	r	= D11*.06	Flange Radius	ft	$d_i\ f$ {assign f = 0.06}
O	w	= D11/2-N11	Flange Center Horiz'l Offset	ft	$(d_i / 2) - r$
P	L	= D11-N11	Flange Center radius	ft	$d_i - r$
Q	ϕ_r	= ASIN(O11/P11)	Crown half angle	radians	$\text{asin}(w / L)$
R	ϕ_d	= Q11*57.29578	" " "	degrees	$180\ \phi_r / \pi$
S	h	= P11*COS(Q11)	Flange Center Vertical Offset	ft	$L \cos\phi$
T	C	= M11-S11	Crown Height	ft	$R - h$
U	θ_r	= 90/57.29578-Q11	Flange Arc Angle	radians	$(\pi / 2) - \phi_r$
V	θ_d	= U11*57.29578	" " "	degrees	$90 - \phi_r$
W	V_c	= PI/3*T11^2*(3*M11-T11)	Crown Volume	cu ft	$(\pi / 3)\ C^2\ (3\ R - C)$
X	V_f	= PI*(D11^2/4*N11*SIN(U11)-1/3*(N11*SIN(U11))^3)	Flange Disk Volume	cu ft	$\pi\ ((d/4)\ r \sin\theta - (1/3)(r \sin\theta)^3)$
Y	V_e	= 2*(W11+X11)	End Bells Volume	cu ft	$2\ (V_c + V_f)$
Z	V_{cs}	= C11-Y11	Volume of Cylindrical Section	cu ft	$V_i - V_e$
AA	L_c	= 4*Z11/PI/D11^2	Length of Cylindrical Section	ft	$4\ V_c / (\pi\ d_i^2)$
AB	L_t	= AA11+2*(T11+N11*SIN(U11))	Total Buoy Length	ft	$L_c + 2\ (C + r \sin\theta)$
AC	M	= (3+(M11/N11)^.5)/4	Knuckle Stress Factor	-	$(3 + (R / r)^{1/2}) / 4$
AD	t_e	= I11*.446*D11*12*AC11/(2*J11*1000+I11*.446*(AC11-.2))	End Bell Thickness	in	$12\ P\ d_i\ M / (2\ S_a + (P\ (M - 0.02)))$
AE	l_1	= 2*PI*M11*R11/360	area calc parameter	ft	$2\ \pi\ R\ \phi / 360$
AF	c_1	= 2*D11*SIN(Q11/2)	"	ft	$2\ R \sin(\phi / 2)$
AG	d_1	= D11*AF11/AE11	"	ft	$R\ c_1 / l_1$
AH	s_1	= D11*SIN(Q11/2)	"	ft	$d_1 \sin(\phi / 2)$
AI	l_2	= 2*PI*N11*V11/360	"	ft	$2\ \pi\ r\ \theta / 360$
AJ	c_2	= 2*N11*SIN(U11/2)	"	ft	$2\ r \sin(\theta / 2)$
AK	d_2	= N11*AJ11/AI11	"	ft	$r\ c_2 / l_2$
AL	s_2	= AK11*COS(U11/2)+O11	"	ft	$d_2 \cos(\theta / 2) + w$
AM	X	= ((AE11*AH11)+(AI11*AL11))/(AE11+AI11)	End Bell Profile CG radius	ft	$(l_1\ s_1) + (l_2\ s_2) / (l_1 + l_2)$
AN	A_{es}	= 4*PI*AM11*(AE11+AI11)	End Bell Surface Area	sq ft	$4\ X\ (l_1 + l_2)$
AO	A_{cs}	= (D11/2)^2*PI	Cylinder Cross Section Area	sq ft	$\pi\ (d_i / 2)^2$
AP	A_{sc}	= PI*D11*AA11	Cylinder Surface Area	sq ft	$\pi\ d_i\ L_c$
AQ	W_c	= AP11*K11*40.8	Cylinder Weight	lb	$40.8\ A_{sc}\ t_c$
AR	W_e	= AN11*AD11*40.8*2	End Bell Weight	lb	$40.8\ A_{es}\ t_e$
AS	W_b	= AQ11+2*AR11	Individual Buoy Weight	lb	$W_c + 2\ W_e$
AT	B	= A11-(3*AS11+.87*5.1*(AB11*PI*AB11+2*PI*E11^2/4))	Net Buoyancy	lb	$D_g - (3\ B + 4.437(L_f\ \pi\ D_f + 2\ \pi D_f^2 / 4)$
AU	E	= 100-(((A11-AT11)/A11)*100)	Efficiency	%	$100 - (100\ (D_g - B) / D_g)$

Spreadsheet to Evaluate the Characteristics of a Tricylinder Buoy Assembly Using Dished and Flanged End Bells

Displ water pounds Dg	Volume water displ cu ft Vt	Volume of each sub cyl cu ft Vi	diam of each sub cyl ft di	outer diam assy ft D	length assy ft L	Surface Area assy sq ft As	Frontal Area assy sq ft Af	Service depth ft d	Material allowable stress ksi Sa	Cylinder Wall Thickn's in tw	Material thickness flat end in Te
200	3.110420	1.036807	.8494166	1.829643	1.829643	10.51678	3.35	2000	24	.0947099	.5834133
500	7.776050	2.592017	1.152836	2.483208	2.483208	19.37207	6.17	2000	24	.1285412	.7918136
1000	15.55210	5.184033	1.452482	3.128646	3.128646	30.75125	9.79	2000	24	.1619517	.9976227
1200	18.66252	6.220840	1.543492	3.324683	3.324683	34.72564	11.05	2000	24	.1720994	1.060132
1600	24.88336	8.294453	1.698833	3.659287	3.659287	42.06711	13.39	2000	24	.1894199	1.166827
2000	31.10420	10.36807	1.830013	3.941847	3.941847	48.81456	15.54	2000	24	.2040464	1.256926
2500	38.88025	12.96008	1.971321	4.246226	4.246226	56.64428	18.03	2000	24	.2198023	1.353982
5000	77.76050	25.92017	2.483709	5.349909	5.349909	89.91719	28.62	2000	24	.2769336	1.705911
7500	116.6407	38.88025	2.843137	6.124118	6.124118	117.8249	37.50	2000	24	.3170098	1.952780
10000	155.5210	51.84033	3.129277	6.740464	6.740464	142.7346	45.43	2000	24	.3489144	2.149313
12500	194.4012	64.80041	3.370912	7.260944	7.260944	165.6289	52.72	2000	24	.3758567	2.315277
15000	233.2815	77.76050	3.582128	7.715905	7.715905	187.0353	59.54	2000	24	.3994073	2.460349
17500	272.1617	90.72058	3.771002	8.122738	8.122738	207.2787	65.98	2000	24	.4204667	2.590075
20000	311.0420	103.6807	3.942642	8.492452	8.492452	226.5771	72.12	2000	24	.4396046	2.707965
25000	388.8025	129.6308	4.247083	9.148216	9.148216	262.9195	83.69	2000	24	.4735497	2.917066

Dished and Flanged End Bells
Flange and Crown Radii Assigned
-Toro-Sphere with R = D; f = .06 D

Crown radius ft R	flange radius ft r	crown half width ft w	hypotenuse crown ft L	crown half angle radian phi	crown half angle degrees phi	back of crown triangle ft h	Crown height ft c	flange arc radian theta	flange arc degrees theta	Crown Volume cu ft Vc	Flange Volume cu ft Vf	End Bells Volume cu ft Ve	Cylinder Volume cu ft Vc
.8494166	.0509650	.3737433	.7984516	.4871226	27.91007	.7055784	.1438382	1.083674	62.08993	.0520938	.0254255	.1550385	.8817682
1.152836	.0691701	.5072477	1.083666	.4871226	27.91007	.9576172	.1952184	1.083674	62.08993	.1302344	.0635637	.3875962	2.204420
1.452482	.0871449	.6390920	1.365333	.4871226	27.91007	1.206522	.2459598	1.083674	62.08993	.2604688	.1271274	.7751924	4.408841
1.543492	.0926095	.6791366	1.450883	.4871226	27.91007	1.282121	.2613713	1.083674	62.08993	.3125626	.1525529	.9302309	5.290609
1.698833	.1019300	.7474866	1.596903	.4871226	27.91007	1.411157	.2876764	1.083674	62.08993	.4167501	.2034038	1.240308	7.054145
1.830013	.1098008	.8052055	1.720212	.4871226	27.91007	1.520123	.3098900	1.083674	62.08993	.5209377	.2542548	1.550385	8.817682
1.971321	.1182793	.8673813	1.853042	.4871226	27.91007	1.637502	.3338188	1.083674	62.08993	.6511721	.3178184	1.937981	11.02210
2.483709	.1490225	1.092832	2.334687	.4871226	27.91007	2.063124	.4205854	1.083674	62.08993	1.302344	.6356369	3.875962	22.04420
2.843137	.1705882	1.250980	2.672549	.4871226	27.91007	2.361687	.4814501	1.083674	62.08993	1.953516	.9534553	5.813943	33.06631
3.129277	.1877566	1.376882	2.941521	.4871226	27.91007	2.599373	.5299044	1.083674	62.08993	2.604688	1.271274	7.751924	44.08841
3.370912	.2022547	1.483201	3.168657	.4871226	27.91007	2.800090	.5708222	1.083674	62.08993	3.255860	1.589092	9.689905	55.11051
3.582128	.2149277	1.576137	3.367201	.4871226	27.91007	2.975539	.6065891	1.083674	62.08993	3.907032	1.906911	11.62789	66.13261
3.771002	.2262601	1.659241	3.544742	.4871226	27.91007	3.132429	.6385725	1.083674	62.08993	4.558204	2.224729	13.56587	77.15471
3.942642	.2365585	1.734763	3.706084	.4871226	27.91007	3.275005	.6676377	1.083674	62.08993	5.209377	2.542548	15.50385	88.17682
4.247083	.2548250	1.868716	3.992258	.4871226	27.91007	3.527892	.7191909	1.083674	62.08993	6.511721	3.178184	19.37981	110.2210

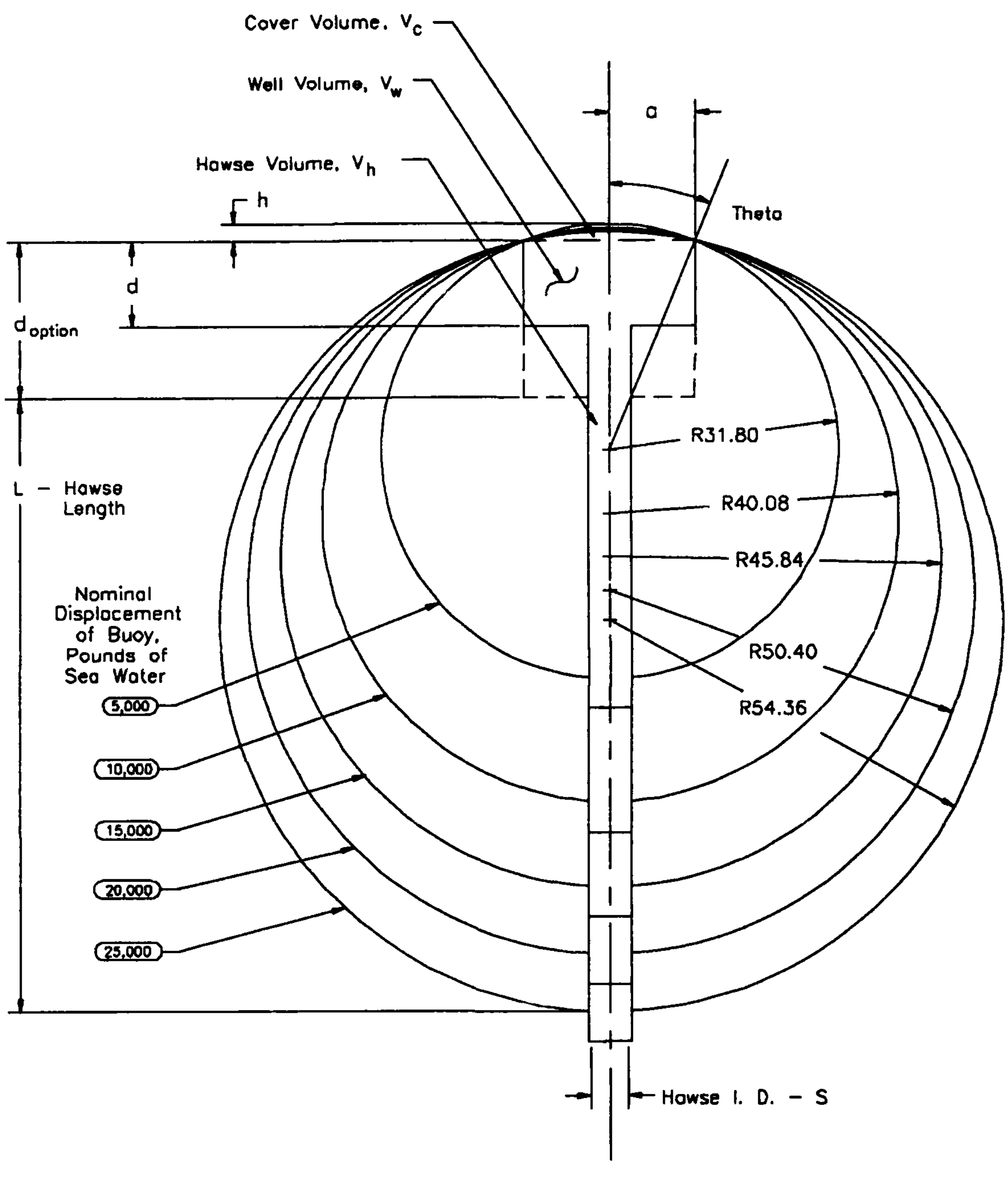
Cylinder Length ft Lc	Buoy Length ft Lb	knuckle stress coeff. M	End bell thickness in te	l1	c1	d1	s1	l2	c2	d2	s2
1.556048	1.933798	1.770621	.3258792	.4137700	.4096912	.8410432	.2048456	.0552294	.0525664	.0485076	.4153028
2.111882	2.624568	1.770621	.4422862	.5615723	.5560365	1.141471	.2780182	.0749579	.0713436	.0658349	.5636526
2.660805	3.306749	1.770621	.5572457	.7075367	.7005620	1.438164	.3502810	.0944410	.0898872	.0829468	.7101578
2.827527	3.513945	1.770621	.5921619	.7518700	.7444582	1.528277	.3722291	.1003585	.0955194	.0881441	.7546552
3.112097	3.867597	1.770621	.6517585	.8275400	.8193823	1.682086	.4096912	.1104589	.1051328	.0970151	.8306055
3.352404	4.166243	1.770621	.7020855	.8914404	.8826529	1.811973	.4413264	.1189882	.1132508	.1045064	.8947427
3.611268	4.487949	1.770621	.7562987	.9602751	.9508090	1.951888	.4754045	.1281761	.1219958	.1125761	.9638324
4.549913	5.654461	1.770621	.9528767	1.209871	1.197944	2.459225	.5989721	.1614918	.1537050	.1418370	1.214353
5.208350	6.472742	1.770621	1.090771	1.384956	1.371304	2.815110	.6856519	.1848620	.1759483	.1623628	1.390087
5.732531	7.124174	1.770621	1.200549	1.524342	1.509315	3.098430	.7546576	.2034669	.1936562	.1787034	1.529988
6.175182	7.674284	1.770621	1.293253	1.642047	1.625860	3.337682	.8129302	.2191781	.2086098	.1925024	1.648130
6.562110	8.155144	1.770621	1.374286	1.744936	1.727735	3.546817	.8638673	.2329115	.2216810	.2045643	1.751400
6.908108	8.585137	1.770621	1.446747	1.836940	1.818832	3.733828	.9094161	.2451921	.2333695	.2153503	1.843745
7.222536	8.975897	1.770621	1.512597	1.920550	1.901618	3.903777	.9508090	.2563523	.2439915	.2251522	1.927665
7.780241	9.668992	1.770621	1.629396	2.068850	2.048456	4.205216	1.024228	.2761471	.2628319	.2425378	2.076514

C.G. Radius X	bells Surface Area sq ft Ase	cross section area cyl sq ft Acs	Cyl Surface Area sq ft Asc	End Cyl weight pounds Wc	cylinder End Bells weight pounds We	Total Buoy Weight pounds Wb	Net Buoyancy pounds B	efficiency of float % E
.2296290	1.353346	.5666715	4.152347	16.04536	35.98784	52.03320	**-31.5580**	**-15.78**
.3116546	2.492886	1.043818	7.648689	40.11340	89.96961	130.0830	**-29.2445**	**-5.85**
.3926601	3.957209	1.656957	12.14154	80.22679	179.9392	260.1660	**-1.13962**	**-.11**
.4172637	4.468652	1.871108	13.71075	96.27215	215.9271	312.1992	14.24434	1.19
.4592581	5.413386	2.266686	16.60939	128.3629	287.9028	416.2656	49.36970	3.09
.4947208	6.281678	2.630256	19.27349	160.4536	359.8784	520.3320	88.75724	4.44
.5329218	7.289241	3.052142	22.36490	200.5670	449.8481	650.4150	142.3296	5.69
.6714394	11.57095	4.844973	35.50207	401.1340	899.6961	1300.830	452.3499	9.05
.7686062	15.16223	6.348710	46.52087	601.7010	1349.544	1951.245	800.8660	10.68
.8459606	18.36774	7.690915	56.35602	802.2679	1799.392	2601.660	1170.892	11.71
.9112835	21.31387	8.924516	65.39537	1002.835	2249.240	3252.075	1555.380	12.44
.9683832	24.06854	10.07795	73.84728	1203.402	2699.088	3902.490	1950.543	13.00
1.019443	26.67356	11.16872	81.84002	1403.969	3148.936	4552.905	2354.050	13.45
1.065844	29.15697	12.20857	89.45961	1604.536	3598.784	5203.320	2764.338	13.82
1.148145	33.83366	14.16679	103.8087	2005.670	4498.481	6504.150	3601.090	14.40

APPENDIX B

CALCULATIONS OF THE PARAMETERS FOR SPHERICAL BUOYS

Spherical Buoy Calculation Parameters and Illustration of Relative Sizes



Subsurface Buoy Parameter Calculations
SuperCalc 3, Ver 2.1
Spreadsheet Equations by Column Letter Designation

COLUMN	SYMBOL SUPERCALC EXPRESSION	EQUATION	DESCRIPTION	UNITS
B	B = 5000	Input Value	Gross Displacement,	lb.
C	V = B13/64.3	B/64.3	displacement,	ft^3
D	R = (3*C13/4/D3)^(1/3)	$[3*V/4/Pi]^{1/3}$	buoy radius,	ft
E	r = D13*12	12*R	buoy radius,	in
F	a = 15	Input Value	well Radius,	in
G	d = 12	Input Value	well Depth,	in
H	Vw = (F13^2)*D3*G13	$Pi*a^2*R*d$	well volume,	in^3
I	i = ASIN(F13/E13)	asin[a/r]	arc subtended by cover,	deg
J	h = E13*(1-COS(I13))	r[1-cos i]	cover height,	in
K	Vc = D3*J13/6*((J13^2)+(3*(F13^2)))	$Pi*h/6[h^2+3a^2]$	cover volume,	in^3
L	s = 6.00	Input Value	hawse Inside Diameter,	in
M	L = 2*E13-(G13+J13)	2*r-[d+h]	hawse length,	in
N	Vh = D3*L13^2*M13/4	$Pi*s^2*L/4$	hawse volume	in^3
O	Vv = H13+K13+N13	Vw+Vc+Vh	Sum of void volumes,	in^3
P	Vn = (C13*1728)-O13	V*1728-Vv	Net Buoy volume,	in^3
Q	Va = (C13*1728)+O13	V*1728+Vv	Adjusted Buoy volume,	in^3
R	r' = (3*Q13/4/D3)^(1/3)	$[3*Va/4/Pi]^{1/3}$	adjusted buoy radius,	in
S	i' = ASIN(F13/R13)	asin[a/r']	adjusted cover arc,	deg
T	h' = R13*(1-COS(S13))	r'[1-cos i']	adjusted cover height,	in
U	Vc = D3*T13/6*(T13^2+3*F13^2)	$Pi*h'/6[h'^2+3\ a^2]$	adjusted cover volume,	in^3
V	L' = 2*R13-(G13+T13)2*	r'-[d+h']	adjusted hawse length,	in
W	Vh'= D3*V13*L13^2/4	$Pi*Vc'*s^2/4$	adjusted hawse volume,	in^3
X	Vf = Q13-(K13+U13+W13)	Va-[Vw+Vc'+Vh']	final sphere volume,	in^3
Y	Df = X13/1728*64.3	Vf*1728/64.3	final sphere water displacement,	lb
Z	E = 2000	Input Value	Max Working Depth,	ft
AA	p = Z13*.446	E*0.446	working pressure,	psi
AB	z = 24000	Input Value	Allowable Stress,	ksi
AC	ts = AA13*R13/2/AB13	12*p*r'/24/z	Sphere Wall Thickness,	in
AD	As = 4*D3*R13^2/144	$4*Pi*r'^2/144$	Sphere surface area,	ft^2
AE	Ws = 40.8*AD13*AC13	40.8*As*ts	Sphere shell weight,	lb
AF	tw = AA13*F13/2/AB13	p*a/2/z	Well wall thickness,	in
AG	Aw = F13*2*D3*G13	2*a*Pi*d	Well wall area,	in^2
AH	Ww = AF13*AG13*40.8/144	tw*Aw*40.8/144	Well wall weight,	lb
AI	tb = (.147*AA13*(F13^2)/24000)^.5	$[0.147*p*a^2/z]^{1/2}$	Well bottom thickness,	in
AJ	Ab = D3*((F13^2)-((L13/2)^2))	$[Pi(a^2-Vc/2)]^{1/2}$	Well bottom area,	in^2
AK	Wb = AJ13*40.8/144	Ab*40.8/144	Well bottom weight,	lb
AL	th = AA13*(L13/2)/48000	p*s/4/z	Hawse tube thickness,	in
AM	Wh = L13*D3*AL13*40.8/144*M13	Pi*s*th*40.8/144/L	Hawse tube weight,	lb
AN	W = AE13+AH13+AK13+AM13	Ws+Ww+Wb+Wh	Total Buoy Weight,	lb
AO	Bn = Y13-AN13	Df-W	Net Buoyancy,	lb
AP	D = 2*R13/12	2*r'/12	Final Buoy Diameter,	ft
AQ	E = 100-(100*(B13-AO13)/B13)	100 -(100(B-Bn)/B)	Efficiency,	%

Gross Buoyancy	Displa-cement	Outside Radius	trial buoy radius	selected Well radius	selected Well Depth	Well Volume	Cover Arc	Cover Height	Cover Volume	Hawse I.D.	Hawse Length	Hawse Volume	Total Voids
B	V	R	r	a	d	Vw	theta	h	Vc	s	L	Vh	Vv
pounds	cu ft	ft	in	in	in	cu in	rad	in	cu in	in	in	cu in	cu in
Small SphericalBuoy Sizes with NO internal Voids													
1000	15.55210	1.548461	18.58153	.00	.00	0	0	0	0	.00	37.16305	0	0
1200	18.66252	1.645485	19.74582	.00	.00	0	0	0	0	.00	39.49164	0	0
1500	23.32815	1.772545	21.27054	.00	.00	0	0	0	0	.00	42.54108	0	0
1667	25.92535	1.836025	22.03230	.00	.00	0	0	0	0	.00	44.06461	0	0
2000	31.10420	1.950938	23.41126	.00	.00	0	0	0	0	.00	46.82251	0	0
2500	38.88025	2.101584	25.21901	.00	.00	0	0	0	0	.00	50.43802	0	0
3000	46.65630	2.233267	26.79920	.00	.00	0	0	0	0	.00	53.59840	0	0
3500	54.43235	2.351019	28.21223	.00	.00	0	0	0	0	.00	56.42446	0	0
4000	62.20840	2.458028	29.49633	.00	.00	0	0	0	0	.00	58.99267	0	0
4500	69.98445	2.556452	30.67742	.00	.00	0	0	0	0	.00	61.35485	0	0
Plain Spherical Buoys with NO Voids													
5000	77.76050	2.647830	31.77396	.00	.00	0	0	0	0	.00	63.54793	0	0
7000	108.8647	2.962098	35.54518	.00	.00	0	0	0	0	.00	71.09036	0	0
9000	139.9689	3.220928	38.65113	.00	.00	0	0	0	0	.00	77.30226	0	0
10000	155.5210	3.336057	40.03268	.00	.00	0	0	0	0	.00	80.06537	0	0
12000	186.6252	3.545090	42.54108	.00	.00	0	0	0	0	.00	85.08215	0	0
15000	233.2815	3.818832	45.82598	.00	.00	0	0	0	0	.00	91.65197	0	0
17000	264.3857	3.981528	47.77834	.00	.00	0	0	0	0	.00	95.55667	0	0
20000	311.0420	4.203169	50.43802	.00	.00	0	0	0	0	.00	100.8760	0	0
22000	342.1462	4.338847	52.06617	.00	.00	0	0	0	0	.00	104.1323	0	0
25000	388.8025	4.527726	54.33271	.00	.00	0	0	0	0	.00	108.6654	0	0
Re-calculate Small Buoy Sizes with 12 in deep by 30 in dia Voids Included													
1000	15.55210	1.548461	18.58153	15.00	12.00	8482.300	.9394835	7.614616	2922.403	6.00	17.54844	496.1704	11900.87
1200	18.66252	1.645485	19.74582	15.00	12.00	8482.300	.8627817	6.904582	2612.631	6.00	20.58705	582.0852	11677.02
1500	23.32815	1.772545	21.27054	15.00	12.00	8482.300	.7827063	6.189564	2311.732	6.00	24.35151	688.5228	11482.55
1667	25.92535	1.836025	22.03230	15.00	12.00	8482.300	.7488795	5.894695	2190.604	6.00	26.16991	739.9369	11412.84
2000	31.10420	1.950938	23.41126	15.00	12.00	8482.300	.6954323	5.436638	2005.604	6.00	29.38587	830.8660	11318.77
2500	38.88025	2.101584	25.21901	15.00	12.00	8482.300	.6370036	4.945913	1811.379	6.00	33.49211	946.9671	11240.65
3000	46.65630	2.233267	26.79920	15.00	12.00	8482.300	.5940457	4.591159	1673.321	6.00	37.00724	1046.355	11201.98
3500	54.43235	2.351019	28.21223	15.00	12.00	8482.300	.5605880	4.318090	1568.296	6.00	40.10637	1133.981	11184.58
4000	62.20840	2.458028	29.49633	15.00	12.00	8482.300	.5334857	4.098820	1484.698	6.00	42.89385	1212.795	11179.79
4500	69.98445	2.556452	30.67742	15.00	12.00	8482.300	.5108959	3.917298	1415.962	6.00	45.43755	1284.716	11182.98
Set Well Depth to 12 inches, Set Well Diameter to 30 inches													
5000	77.76050	2.647830	31.77396	15.00	12.00	8482.300	.4916540	3.763523	1358.050	6.00	47.78440	1351.072	11191.42
7000	108.8647	2.962098	35.54518	15.00	12.00	8482.300	.4356482	3.320037	1192.559	6.00	55.77033	1576.869	11251.73
9000	139.9689	3.220928	38.65113	15.00	12.00	8482.300	.3985549	3.029369	1085.224	6.00	62.27290	1760.725	11328.25
10000	155.5210	3.336057	40.03268	15.00	12.00	8482.300	.3840665	2.916437	1043.742	6.00	65.14893	1842.043	11368.09
12000	186.6252	3.545090	42.54108	15.00	12.00	8482.300	.3603485	2.732243	976.3342	6.00	70.34991	1989.097	11447.73
15000	233.2815	3.818832	45.82598	15.00	12.00	8482.300	.3334715	2.524473	900.6464	6.00	77.12750	2180.729	11563.68
17000	264.3857	3.981528	47.77834	15.00	12.00	8482.300	.3193503	2.415693	861.1575	6.00	81.14098	2294.207	11637.66
20000	311.0420	4.203169	50.43802	15.00	12.00	8482.300	.3019627	2.282087	812.7791	6.00	86.59396	2448.386	11743.47
22000	342.1462	4.338847	52.06617	15.00	12.00	8482.300	.2922368	2.207509	785.8307	6.00	89.92483	2542.565	11810.70
25000	388.8025	4.527726	54.33271	15.00	12.00	8482.300	.2797098	2.111609	751.2341	6.00	94.55382	2673.446	11906.98
Modify Well Depth to 24 in, diameter remains at 30 in													
4000	62.20840	2.458028	29.49633	15.00	24.00	16964.60	.5334857	4.098820	1484.698	6.00	30.89385	873.5030	19322.80
5000	77.76050	2.647830	31.77396	15.00	24.00	16964.60	.4916540	3.763523	1358.050	6.00	35.78440	1011.780	19334.43
7000	108.8647	2.962098	35.54518	15.00	24.00	16964.60	.4356482	3.320037	1192.559	6.00	43.77033	1237.577	19394.74
9000	139.9689	3.220928	38.65113	15.00	24.00	16964.60	.3985549	3.029369	1085.224	6.00	50.27290	1421.433	19471.26
10000	155.5210	3.336057	40.03268	15.00	24.00	16964.60	.3840665	2.916437	1043.742	6.00	53.14893	1502.751	19511.09
12000	186.6252	3.545090	42.54108	15.00	24.00	16964.60	.3603485	2.732243	976.3342	6.00	58.34991	1649.805	19590.74
15000	233.2815	3.818832	45.82598	15.00	24.00	16964.60	.3334715	2.524473	900.6464	6.00	65.12750	1841.437	19706.68
17000	264.3857	3.981528	47.77834	15.00	24.00	16964.60	.3193503	2.415693	861.1575	6.00	69.14098	1954.915	19780.67
20000	311.0420	4.203169	50.43802	15.00	24.00	16964.60	.3019627	2.282087	812.7791	6.00	74.59396	2109.094	19886.47
22000	342.1462	4.338847	52.06617	15.00	24.00	16964.60	.2922368	2.207509	785.8307	6.00	77.92483	2203.273	19953.70
25000	388.8025	4.527726	54.33271	15.00	24.00	16964.60	.2797098	2.111609	751.2341	6.00	82.55382	2334.154	20049.99
Set Allowable Stress to 36ksi, Well Depth to 12 inches													
5000	77.76050	2.647830	31.77396	15.00	12.00	8482.300	.4916540	3.763523	1358.050	6.00	47.78440	1351.072	11191.42
7000	108.8647	2.962098	35.54518	15.00	12.00	8482.300	.4356482	3.320037	1192.559	6.00	55.77033	1576.869	11251.73
9000	139.9689	3.220928	38.65113	15.00	12.00	8482.300	.3985549	3.029369	1085.224	6.00	62.27290	1760.725	11328.25
10000	155.5210	3.336057	40.03268	15.00	12.00	8482.300	.3840665	2.916437	1043.742	6.00	65.14893	1842.043	11368.09
12000	186.6252	3.545090	42.54108	15.00	12.00	8482.300	.3603485	2.732243	976.3342	6.00	70.34991	1989.097	11447.73
15000	233.2815	3.818832	45.82598	15.00	12.00	8482.300	.3334715	2.524473	900.6464	6.00	77.12750	2180.729	11563.68
17000	264.3857	3.981528	47.77834	15.00	12.00	8482.300	.3193503	2.415693	861.1575	6.00	81.14098	2294.207	11637.66
20000	311.0420	4.203169	50.43802	15.00	12.00	8482.300	.3019627	2.282087	812.7791	6.00	86.59396	2448.386	11743.47
22000	342.1462	4.338847	52.06617	15.00	12.00	8482.300	.2922368	2.207509	785.8307	6.00	89.92483	2542.565	11810.70
25000	388.8025	4.527726	54.33271	15.00	12.00	8482.300	.2797098	2.111609	751.2341	6.00	94.55382	2673.446	11906.98

Sphere Net Volume	Adjust Gross Volume	Adjust Outside Radius	Adjust Cover Arc	Adjust Cover Height	Adjust Cover Volume	Adjust Hawse Length	Adjust Hawse Volume	Sphere Final Volume	Final Displa-cement	work press.	stress allowable	Sphere shell thick	sphere surface area
Vn	Va	r'	theta'	h'	Vc'	L'	Vh'	Vf	Df	p	z	ts	As
cu in	cu in	in	deg	in	cu in	in	cu in	cu in	pounds	psi	psi	in	sq ft
Small Spherical Buoy Sizes with NO internal Voids (continued)													
26874.03	26874.03	18.58153	0	0	0	37.16305	0	26874.03	1000	892	24000	.3453067	30.13076
32248.83	32248.83	19.74582	0	0	0	39.49164	0	32248.83	1200	892	24000	.3669431	34.02496
40311.04	40311.04	21.27054	0	0	0	42.54108	0	40311.04	1500	892	24000	.3952775	39.48247
44799.00	44799.00	22.03230	0	0	0	44.06461	0	44799.00	1667	892	24000	.4094337	42.36110
53748.06	53748.06	23.41126	0	0	0	46.82251	0	53748.06	2000	892	24000	.4350592	47.82961
67185.07	67185.07	25.21901	0	0	0	50.43802	0	67185.07	2500	892	24000	.4686533	55.50134
80622.08	80622.08	26.79920	0	0	0	53.59840	0	80622.08	3000	892	24000	.4980184	62.67451
94059.10	94059.10	28.21223	0	0	0	56.42446	0	94059.10	3500	892	24000	.5242773	69.45798
107496.1	107496.1	29.49633	0	0	0	58.99267	0	107496.1	4000	892	24000	.5481402	75.92477
120933.1	120933.1	30.67742	0	0	0	61.35485	0	120933.1	4500	892	24000	.5700888	82.12685
Plain Spherical Buoys with NO Voids (continued)													
134370.1	134370.1	31.77396	0	0	0	63.54793	0	134370.1	5000	892	24000	.5904661	88.10289
188118.2	188118.2	35.54518	0	0	0	71.09036	0	188118.2	7000	892	24000	.6605479	110.2577
241866.3	241866.3	38.65113	0	0	0	77.30226	0	241866.3	9000	892	24000	.7182669	130.3682
268740.3	268740.3	40.03268	0	0	0	80.06537	0	268740.3	10000	892	24000	.7439407	139.8546
322488.3	322488.3	42.54108	0	0	0	85.08215	0	322488.3	12000	892	24000	.7905550	157.9299
403110.4	403110.4	45.82598	0	0	0	91.65197	0	403110.4	15000	892	24000	.8515995	183.2614
456858.5	456858.5	47.77834	0	0	0	95.55667	0	456858.5	17000	892	24000	.8878808	199.2092
537480.6	537480.6	50.43802	0	0	0	100.8760	0	537480.6	20000	892	24000	.9373066	222.0054
591228.6	591228.6	52.06617	0	0	0	104.1323	0	591228.6	22000	892	24000	.9675629	236.5694
671850.7	671850.7	54.33271	0	0	0	108.6654	0	671850.7	25000	892	24000	1.009683	257.6144
Re-calculate Small Buoy Sizes with 12 in deep by 30 in dia Voids Included (continued)													
14973.15	38774.90	20.99684	.7957563	6.304415	2359.364	23.68927	669.7984	27263.44	1014.490	892	24000	.3901914	38.47295
20571.82	43925.85	21.88822	.7550156	5.947887	2212.333	25.82856	730.2853	32500.93	1209.381	892	24000	.4067562	41.80887
28828.49	51793.60	23.12397	.7058453	5.525162	2041.068	28.72279	812.1177	40458.11	1505.473	892	24000	.4297205	46.66297
33386.16	56211.85	23.76365	.6831204	5.332399	1964.015	30 19489	853.7405	44911.79	1671.197	892	24000	.4416078	49.28032
42429.29	65066.83	24.95114	.6449707	5.012249	1837.407	32.89002	929.9435	53817.18	2002.572	892	24000	.4636753	54.32854
55944.42	78425.72	26.55359	.6003064	4.642562	1693.209	36.46462	1031.013	67219.19	2501.270	892	24000	.4934543	61.53100
69420.11	91824.06	27.98698	.5656487	4.359221	1584.049	39.61473	1120.080	80637.63	3000.579	892	24000	.5200913	68.35327
82874.52	105243.7	29.28886	.5376746	4.132602	1497.537	42.44512	1200.107	94063.73	3500.172	892	24000	.5442846	74.86043
96316.32	118675.9	30.48536	.5144309	3.945632	1426.664	45.02509	1273.054	107493.9	3999.917	892	24000	.5665196	81.10171
109750.1	132116.1	31.59529	.4946848	3.787694	1367.134	47.40289	1340.285	120926.4	4499.749	892	24000	.5871459	87.11484
Set Well Depth to 12 inches, Set Well Diameter to 30 inches (continued)													
123178.7	145561.6	32.63268	.4776145	3.651794	1316.149	49.61356	1402.790	141484.6	5264.733	892	24000	.6064239	92.92932
176866.5	199369.9	36.24018	.4267399	3.250020	1166.626	57.23034	1618.150	195392.6	7270.685	892	24000	.6734633	114.6115
230538.0	253194.5	39.24538	.3921873	2.979696	1066.963	63.51107	1795.733	241849.5	8999.377	892	24000	.7293100	134.4078
257372.2	280108.4	40.58939	.3785298	2.873365	1027.952	66.30541	1874.741	268723.4	9999.371	892	24000	.7542861	143.7714
311040.6	333936.1	43.03861	.3559962	2.698531	964.0289	71.37869	2018.185	322471.6	11999.38	892	24000	.7998008	161.6456
391546.7	414674.1	46.26005	.3302229	2.499426	891.5456	78.02067	2205.983	403094.3	14999.40	892	24000	.8596659	186.7496
445220.8	468496.1	48.18063	.3165906	2.394463	853.4613	81.96680	2317.557	456842.8	16999.42	892	24000	.8953567	202.5780
525737.1	549224.0	50.80272	.2997274	2.264937	806.5786	87.34050	2469.495	537465.7	19999.45	892	24000	.9440839	225.2274
579417.9	603039.3	52.41058	.2902604	2.192367	780.3639	90.62880	2562.469	591214.2	21999.46	892	24000	.9739634	239.7096
659943.7	683757.7	54.65181	.2780331	2.098786	746.6129	95.20483	2691.853	671836.9	24999.49	892	24000	1.015613	260.6492
Modify Well Depth to 24 in, diameter remains at 30 in (continued)													
88173.31	126818.9	31.16725	.5021080	3.846974	1389.443	34.48752	975.1118	107489.8	3999.764	892	24000	.5791914	84.77042
115035.7	153704.6	33.23018	.4683301	3.578116	1288.597	38.88225	1099.370	134352.0	4999.325	892	24000	.6175276	96.36356
168723.5	207512.9	36.72701	.4207211	3.202791	1149.162	46.25122	1307.722	188091.4	6999.005	892	24000	.6825102	117.7114
222395.0	261337.5	39.66167	.3878499	2.945896	1054.551	52.37745	1480.938	241837.4	8998.927	892	24000	.7370461	137.2744
249229.2	288251.4	40.97896	.3747517	2.844000	1017.197	55.11392	1558.309	268711.3	9998.920	892	24000	.7615257	146.5444
302897.6	342079.1	43.38564	.3530236	2.675522	955.6356	60.09575	1699.167	322459.7	11998.93	892	24000	.8062497	164.2628
383403.7	422817.1	46.56089	.3280089	2.482363	885.3490	66.63942	1884.185	403083.0	14998.98	892	24000	.8652566	189.1864
437077.8	476639.1	48.45817	.3147148	2.380038	848.2340	70.53631	1994.367	456831.9	16999.01	892	24000	.9005144	204.9186
517594.1	557367.0	51.05256	.2982154	2.253340	802.3867	75.85179	2144.659	537455.4	19999.06	892	24000	.9487268	227.4482
571274.9	611182.3	52.64544	.2889282	2.182163	776.6808	79.10871	2236.746	591204.3	21999.09	892	24000	.9783277	241.8627
651800.7	691900.7	54.86791	.2769092	2.090192	743.5162	83.64562	2365.024	671827.5	24999.14	892	24000	1.019629	262.7146
Set Allowable Stress to 36ksi, Well Depth to 12 inches (continued)													
123178.7	145561.6	32.63268	.4776145	3.651794	1316.149	49.61356	1402.790	134360.3	4999.635	892	36000	.4042826	92.92932
176866.5	199369.9	36.24018	.4267399	3.250020	1166.626	57.23034	1618.150	188102.8	6999.429	892	36000	.4489756	114.6115
230538.0	253194.5	39.24538	.3921873	2.979696	1066.963	63.51107	1795.733	241849.5	8999.377	892	36000	.4862067	134.4078
257372.2	280108.4	40.58939	.3785298	2.873365	1027.952	66.30541	1874.741	268723.4	9999.371	892	36000	.5028574	143.7714
311040.6	333936.1	43.03861	.3559962	2.698531	964.0289	71.37869	2018.185	322471.6	11999.38	892	36000	.5332006	161.6456
391546.7	414674.1	46.26005	.3302229	2.499426	891.5456	78.02067	2205.983	403094.3	14999.40	892	36000	.5731106	186.7496
445220.8	468496.1	48.18063	.3165906	2.394463	853.4613	81.96680	2317.557	456842.8	16999.42	892	36000	.5969045	202.5780
525737.1	549224.0	50.80272	.2997274	2.264937	806.5786	87.34050	2469.495	537465.7	19999.45	892	36000	.6293893	225.2274
579417.9	603039.3	52.41058	.2902604	2.192367	780.3639	90.62880	2562.469	591214.2	21999.46	892	36000	.6493089	239.7096
659943.7	683757.7	54.65181	.2780331	2.098786	746.6129	95.20483	2691.853	671836.9	24999.49	892	36000	.6770752	260.6492

sphere shell weight	well wall thick	well wall area	well wall weight	well bottom thick	well bottom area	well bottom weight	hawse tube thick	hawse tube weight	sum buoy weight	net buoy-ancy	Buoy Diam-eter	Effic-iency
Ws	tw	Aw	Ww	tb	Ab	Wb	th	Wh	W	Bn	D	E
lb	in	aq in	lb	in	sq in	lb	in	lb	pounds	pounds	ft	%
Small Spherical Buoy Sizes with NO internal Voids (continued)												
424.4977	0	0	0	0	0	0	0	0	424.4977	575.5023	3.096921	57.55
509.3972	0	0	0	0	0	0	0	0	509.3972	690.6028	3.290970	57.55
636.7465	0	0	0	0	0	0	0	0	636.7465	863.2535	3.545090	57.55
707.6376	0	0	0	0	0	0	0	0	707.6376	959.3624	3.672051	57.55
848.9953	0	0	0	0	0	0	0	0	848.9953	1151.005	3.901876	57.55
1061.244	0	0	0	0	0	0	0	0	1061.244	1438.756	4.203169	57.55
1273.493	0	0	0	0	0	0	0	0	1273.493	1726.507	4.466533	57.55
1485.742	0	0	0	0	0	0	0	0	1485.742	2014.258	4.702038	57.55
1697.991	0	0	0	0	0	0	0	0	1697.991	2302.009	4.916056	57.55
1910.240	0	0	0	0	0	0	0	0	1910.240	2589.760	5.112904	57.55
Plain Spherical Buoys with NO Voids (continued)												
2122.488	0	0	0	0	0	0	0	0	2122.488	2877.512	5.295661	57.55
2971.484	0	0	0	0	0	0	0	0	2971.484	4028.516	5.924197	57.55
3820.479	0	0	0	0	0	0	0	0	3820.479	5179.521	6.441855	57.55
4244.977	0	0	0	0	0	0	0	0	4244.977	5755.023	6.672114	57.55
5093.972	0	0	0	0	0	0	0	0	5093.972	6906.028	7.090179	57.55
6367.465	0	0	0	0	0	0	0	0	6367.465	8632.535	7.637664	57.55
7216.460	0	0	0	0	0	0	0	0	7216.460	9783.540	7.963056	57.55
8489.953	0	0	0	0	0	0	0	0	8489.953	11510.05	8.406337	57.55
9338.949	0	0	0	0	0	0	0	0	9338.949	12661.05	8.677695	57.55
10612.44	0	0	0	0	0	0	0	0	10612.44	14387.56	9.055452	57.55
Re-calculate Small Buoy Sizes with 12 in deep by 30 in dia Voids Included (continued)												
612.4819	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	5.224949	899.2956	115.1946	3.499474	11.52
693.8454	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	6.129681	981.5639	227.8168	3.648037	18.98
818.1230	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	7.250527	1106.962	398.5102	3.853996	26.57
887.9129	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	7.791946	1177.294	493.9031	3.960608	29.63
1027.785	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	8.749481	1318.123	684.4489	4.158523	34.22
1238.800	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	9.972090	1530.360	970.9093	4.425599	38.84
1450.438	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	11.01870	1743.045	1257.533	4.664496	41.92
1662.412	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	11.94145	1955.942	1544.231	4.881477	44.12
1874.585	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	12.77141	2168.945	1830.972	5.080893	45.77
2086.884	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	13.52878	2382.002	2117.748	5.265882	47.06
Set Well Depth to 12 inches, Set Well Diameter to 30 inches (continued)												
2299.266	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	14.22754	2595.083	2669.650	5.438779	53.39
3149.214	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	16.60530	3447.408	3823.277	6.040030	54.62
3999.418	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	18.54141	4299.548	4699.828	6.540897	52.22
4424.545	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	19.39773	4725.532	5273.839	6.764898	52.74
5274.798	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	20.94629	5577.334	6422.042	7.173102	53.52
6550.123	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	22.96428	6854.676	8144.723	7.710008	54.30
7400.287	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	24.15928	7706.035	9293.382	8.030105	54.67
8675.451	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	25.78287	8982.823	11016.62	8.467120	55.08
9525.508	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	26.77462	9833.872	12165.59	8.735097	55.30
10800.52	.27875	1130.973	89.32333	1.108732	678.5840	192.2655	.05575	28.15287	11110.26	13889.22	9.108635	55.56
Modify Well Depth to 24 in, diameter remains at 30 in (continued)												
2003.210	.27875	2261.947	178.6467	1.108732	678.5840	192.2655	.05575	9.198472	2383.321	1616.443	5.194542	40.41
2427.892	.27875	2261.947	178.6467	1.108732	678.5840	192.2655	.05575	10.65461	2809.459	2189.867	5.538364	43.80
3277.840	.27875	2261.947	178.6467	1.108732	678.5840	192.2655	.05575	13.03237	3661.784	3337.220	6.121168	47.67
4128.044	.27875	2261.947	178.6467	1.108732	678.5840	192.2655	.05575	14.96848	4513.924	4485.003	6.610279	49.83
4553.171	.27875	2261.947	178.6467	1.108732	678.5840	192.2655	.05575	15.82480	4939.908	5059.013	6.829827	50.59
5403.424	.27875	2261.947	178.6467	1.108732	678.5840	192.2655	.05575	17.37336	5791.710	6207.224	7.230939	51.73
6678.748	.27875	2261.947	178.6467	1.108732	678.5840	192.2655	.05575	19.39135	7069.052	7929.927	7.760149	52.87
7528.913	.27875	2261.947	178.6467	1.108732	678.5840	192.2655	.05575	20.58634	7920.411	9078.602	8.076362	53.40
8804.077	.27875	2261.947	178.6467	1.108732	678.5840	192.2655	.05575	22.20994	9197.199	10801.86	8.508761	54.01
9654.134	.27875	2261.947	178.6467	1.108732	678.5840	192.2655	.05575	23.20168	10048.25	11950.85	8.774239	54.32
10929.15	.27875	2261.947	178.6467	1.108732	678.5840	192.2655	.05575	24.57994	11324.64	13674.50	9.144651	54.70
Set Allowable Stress to 36ksi, Well Depth to 12 inches (continued)												
1532.844	.1858333	1130.973	59.54889	1.108732	678.5840	192.2655	.05575	14.22754	1798.886	3200.749	5.438779	64.01
2099.476	.1858333	1130.973	59.54889	1.108732	678.5840	192.2655	.05575	16.60530	2367.896	4631.533	6.040030	66.16
2666.279	.1858333	1130.973	59.54889	1.108732	678.5840	192.2655	.05575	18.54141	2936.635	6062.742	6.540897	67.36
2949.697	.1858333	1130.973	59.54889	1.108732	678.5840	192.2655	.05575	19.39773	3220.909	6778.462	6.764898	67.78
3516.532	.1858333	1130.973	59.54889	1.108732	678.5840	192.2655	.05575	20.94629	3789.293	8210.083	7.173102	68.42
4366.749	.1858333	1130.973	59.54889	1.108732	678.5840	192.2655	.05575	22.96428	4641.527	10357.87	7.710008	69.05
4933.525	.1858333	1130.973	59.54889	1.108732	678.5840	192.2655	.05575	24.15928	5209.498	11789.92	8.030105	69.35
5783.634	.1858333	1130.973	59.54889	1.108732	678.5840	192.2655	.05575	25.78287	6061.231	13938.21	8.467120	69.69
6350.339	.1858333	1130.973	59.54889	1.108732	678.5840	192.2655	.05575	26.77462	6628.928	15370.53	8.735097	69.87
7200.[illegible]	.1858333	1130.973	59.54889	1.108732	678.5840	192.2655	.05575	28.15287	7480.315	17519.17	9.108635	70.08

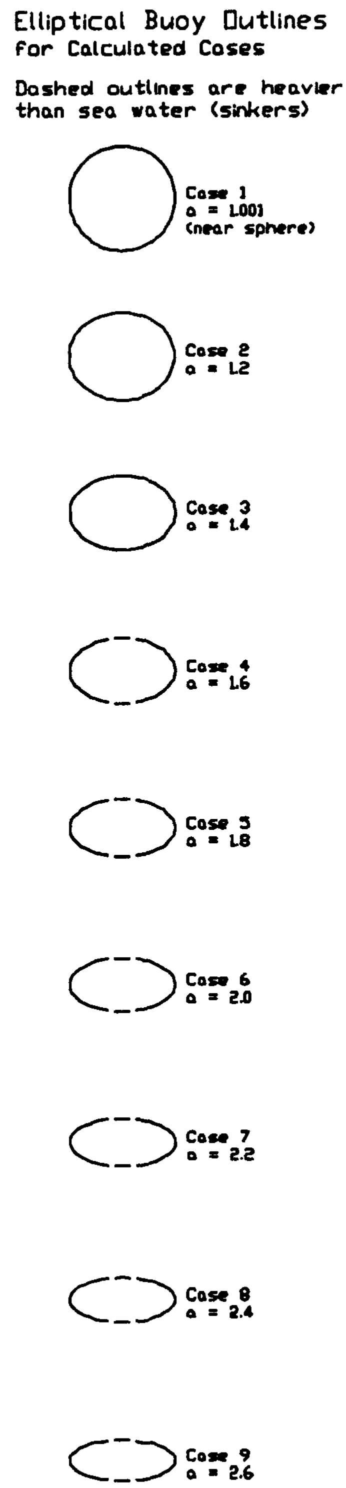
APPENDIX C

CALCULATIONS OF THE PARAMETERS FOR ELLIPSOIDAL BUOYS

Equation Definitions for Calculation of Parameters of an Ellipsoidal Buoy
Expressions Correspond with the Derivations Given with Figure 15.

Column	Quan		Spreadsheet Expression	Description	Formula
A	D_g	=	Assigned	Gross Displacement, pounds	Input
B	V_b	=	A11/64.3	Buoy Volume, pounds	$D_g/64.3$
C	a	=	Assigned	Height Aspect ratio	Input
D	W	=	(3*C11*B11/64.3/4/PI)^(1/3)*2	Diameter, ft	$2(3aV_b/4\pi)^{1/3}$
E	H	=	D11/C11	Buoy Height, ft	W/a
F	w	=	D11/2	Major Radius, ft	W/2
H	b	=	E11/2	Minor Radius, ft	H/2
I	A_v	=	PI*F11*H11	Frontal Area, sq ft	πwb
J	t_1	=	2*PI*F11^2	parameter	$2\pi w^2$
K	e	=	((F11^2-H11^2)^.5)/F11	Eccentricity, ratio	$((w^2-b^2)^{1/2})/w$
L	t_2	=	LN((1+K11)/(1-K11))*H11^2/K11*Pi	parameter	$\pi b^2/e \ln((1+e)/(1-e))$
M	A_s	=	J11+L11	Surface Area, sq ft	$t_1 + t_2$
N	A_s	=	5.2*F11*H11*PI	surface area (empirical), sq ft	$5.2\pi wb$
O	d_w	=	2000	Water Depth, feet	assigned
P	S_a	=	24000	Allowable Material Stress, ksi	assigned
Q	t	=	O11*.446*D11*12/((2*P11*1)+(1.8*.446*O11))	Shell Thickness, inches	$.446d_w12W/(2S_a+.8028d_w)$
R	W_b	=	M11*Q 11*40.8	Buoy Weight, lb	$40.8A_st$
S	B	=	B11-R 11	Net Buoyancy, pounds	V_b-W_b
T	W_{st}	=	5.1*M11	Thin Shell weight, pounds	$5.1A_s$
U	E	%	100-(100(A11-S11)/A11)	Efficiency, %	$100 - (100 (D_g - B) / D_g)$

Elliptical Buoy Outlines for Calculated Cases



Spreadsheet to Evaluate the Properties of an Ellipsoidal Buoy

displaced volume Vb lb	aspect ratio a	Diameter W ft	Height H ft	major semi-axis w ft	minor semi-axis b ft	frontal area Af sq ft	t-1	eccentricity e	t-2	Surface Area As sq ft	Empirical eqn area As sq ft	Working depth assign ft	material allowable stress Sa psi
NEAR SPHERE PROPORTION; W:H ALMOST 1:1													
500	1.001	2.458847	2.456391	1.229423	1.228195	4.743717	9.496922	.0446879	9.484273	18.98120	24.66733	2000	24000
1000	1.001	3.097953	3.094858	1.548977	1.547429	7.530182	15.07542	.0446879	15.05535	30.13077	39.15695	2000	24000
2000	1.001	3.903176	3.899277	1.951588	1.949638	11.95342	23.93074	.0446879	23.89887	47.82961	62.15778	2000	24000
4000	1.001	4.917694	4.912781	2.458847	2.456391	18.97487	37.98769	.0446879	37.93709	75.92478	98.66932	2000	24000
6000	1.001	5.629354	5.623730	2.814677	2.811865	24.86411	49.77795	.0446879	49.71166	99.48961	129.2934	2000	24000
8000	1.001	6.195906	6.189716	3.097953	3.094858	30.12073	60.30170	.0446879	60.22138	120.5231	156.6278	2000	24000
10000	1.001	6.674337	6.667670	3.337169	3.333835	34.95201	69.97392	.0446879	69.88072	139.8546	181.7504	2000	24000
12000	1.001	7.092542	7.085456	3.546271	3.542728	39.46932	79.01757	.0446879	78.91233	157.9299	205.2405	2000	24000
15000	1.001	7.640209	7.632577	3.820105	3.816288	45.80009	91.69177	.0446879	91.56965	183.2614	238.1604	2000	24000
20000	1.001	8.409138	8.400738	4.204569	4.200369	55.48285	111.0767	.0446879	110.9287	222.0054	288.5108	2000	24000
25000	1.001	9.058470	9.049420	4.529235	4.524710	64.38215	128.8931	.0446879	128.7214	257.6145	334.7872	2000	24000
ASPECT RATIO = 1:1.2													
500	1.2	2.612044	2.176704	1.306022	1.088352	4.465496	10.71719	.5527708	8.379475	19.09667	23.22058	2000	24000
1000	1.2	3.290970	2.742475	1.645485	1.371237	7.088534	17.01248	.5527708	13.30159	30.31407	36 86037	2000	24000
2000	1.2	4.146362	3.455302	2.073181	1.727651	11.25235	27.00563	.5527708	21.11495	48.12058	58.51220	2000	24000
4000	1.2	5.224089	4.353407	2.612044	2.176704	17.86199	42.86876	.5527708	33.51790	76.38667	92.88232	2000	24000
6000	1.2	5.980089	4.983407	2.990044	2.491704	23.40582	56.17397	.5527708	43.92087	100.0948	121.7103	2000	24000
8000	1.2	6.581939	5.484949	3.290970	2.742475	28.35413	68.04992	.5527708	53.20635	121.2563	147.4415	2000	24000
10000	1.2	7.090179	5.908483	3.545090	2.954241	32.90206	78.96494	.5527708	61.74050	140.7054	171.0907	2000	24000
12000	1.2	7.534440	6.278700	3.767220	3.139350	37.15443	89.17062	.5527708	69.72004	158.8907	193.2030	2000	24000
15000	1.2	8.116229	6.763524	4.058115	3.381762	43.11389	103.4733	.5527708	80.90294	184.3763	224.1922	2000	24000
20000	1.2	8.933066	7.444222	4.466533	3.722111	52.22876	125.3490	.5527708	98.00694	223.3560	271.5896	2000	24000
25000	1.2	9.622854	8.019045	4.811427	4.009522	60.60611	145.4547	.5527708	113.7270	259.1816	315.1518	2000	24000
ASPECT RATIO = 1:1.4													
500	1.4	2.749769	1.964120	1.374884	.9820602	4.241839	11.87715	.6998542	7.507148	19.38430	22.05756	2000	24000
1000	1.4	3.464491	2.474637	1.732246	1.237318	6.733499	18.85380	.6998542	11.91686	30.77065	35.01420	2000	24000
2000	1.4	4.364986	3.117847	2.182493	1.558923	10.68876	29.92854	.6998542	18.91683	48.84537	55.58157	2000	24000
4000	1.4	5.499537	3.928241	2.749769	1.964120	16.96735	47.50859	.6998542	30.02859	77.53719	88.23024	2000	24000
6000	1.4	6.295399	4.496713	3.147699	2.248357	22.23352	62.25387	.6998542	39.34859	101.6025	115.6143	2000	24000
8000	1.4	6.928983	4.949273	3.464491	2.474637	26.93400	75.41519	.6998542	47.66742	123.0826	140.0568	2000	24000
10000	1.4	7.464020	5.331443	3.732010	2.665722	31.25413	87.51158	.6998542	55.31314	142.8247	162.5215	2000	24000
12000	1.4	7.931705	5.665504	3.965853	2.832752	35.29352	98.82185	.6998542	62.46199	161.2838	183.5263	2000	24000
15000	1.4	8.544170	6.102979	4.272085	3.051489	40.95450	114.6726	.6998542	72.48072	187.1533	212.9634	2000	24000
20000	1.4	9.404076	6.717197	4.702038	3.358599	49.61285	138.9160	.6998542	87.80414	226.7201	257.9868	2000	24000
25000	1.4	10.13023	7.235882	5.065117	3.617941	57.57061	161.1977	.6998542	101.8877	263.0854	299.3672	2000	24000
ASPECT RATIO = 1:1.6													
500	1.6	2.874927	1.796829	1.437463	.8984146	4.057173	12.98295	.7806247	6.801811	19.78476	21.09730	2000	24000
1000	1.6	3.622181	2.263863	1.811090	1.131932	6.440360	20.60915	.7806247	10.79720	31.40635	33.48987	2000	24000
2000	1.6	4.563662	2.852289	2.281831	1.426144	10.22343	32.71499	.7806247	17.13949	49.85448	53.16186	2000	24000
4000	1.6	5.749854	3.593659	2.874927	1.796829	16.22869	51.93181	.7806247	27.20724	79.13905	84.38919	2000	24000
6000	1.6	6.581939	4.113712	3.290970	2.056856	21.26560	68.04992	.7806247	35.65158	103.7015	110.5811	2000	24000
8000	1.6	7.244362	4.527726	3.622181	2.263863	25.76144	82.43661	.7806247	43.18881	125.6254	133.9595	2000	24000
10000	1.6	7.803752	4.877345	3.901876	2.438673	29.89350	95.65921	.7806247	50.11617	145.7754	155.4462	2000	24000
12000	1.6	8.292724	5.182952	4.146362	2.591476	33.75704	108.0225	.7806247	56.59335	164.6159	175.5366	2000	24000
15000	1.6	8.933066	5.583166	4.466533	2.791583	39.17157	125.3490	.7806247	65.67076	191.0198	203.6922	2000	24000
20000	1.6	9.832111	6.145070	4.916056	3.072535	47.45298	151.8495	.7806247	79.55446	231.4040	246.7555	2000	24000
25000	1.6	10.59132	6.619576	5.295661	3.309788	55.06431	176.2058	.7806247	92.31478	268.5206	286.3344	2000	24000
ASPECT RATIO = 1:1.8													
500	1.8	2.990044	1.661136	1.495022	.8305679	3.900970	14.04349	.8314794	6.218514	20.26201	20.28505	2000	24000
1000	1.8	3.767220	2.092900	1.883610	1.046450	6.192404	22.29266	.8314794	9.871275	32.16393	32.20050	2000	24000
2000	1.8	4.746400	2.636889	2.373200	1.318444	9.829829	35.38739	.8314794	15.66967	51.05706	51.11511	2000	24000
4000	1.8	5.980089	3.322272	2.990044	1.661136	15.60388	56.17397	.8314794	24.87405	81.04803	81.14018	2000	24000
6000	1.8	6.845493	3.803052	3.422746	1.901526	20.44687	73.60873	.8314794	32.59423	106.2030	106.3237	2000	24000
8000	1.8	7.534440	4.185800	3.767220	2.092900	24.76962	89.17062	.8314794	39.48510	128.6557	128.8020	2000	24000
10000	1.8	8.116229	4.509016	4.058115	2.254508	28.74260	103.4733	.8314794	45.81840	149.2917	149.4615	2000	24000
12000	1.8	8.624781	4.791545	4.312390	2.395772	32.45738	116.8466	.8314794	51.74012	168.5867	168.7784	2000	24000
15000	1.8	9.290763	5.161535	4.645382	2.580768	37.66345	135.5884	.8314794	60.03909	195.6275	195.8500	2000	24000
20000	1.8	10.22581	5.681004	5.112904	2.840502	45.62603	164.2537	.8314794	72.73218	236.9859	237.2553	2000	24000
25000	1.8	11.01542	6.119677	5.507709	3.059838	52.94431	190.5995	.8314794	84.39821	274.9977	275.3104	2000	24000

Spreadsheet to Evaluate the Properties of an Ellipsoidal Buoy

Material thick -ness t in	1/8-in Thin Shell Weight Wbt lb	Buoy Weight Wb lb	Net Buoyancy Bn lb	Effic- iency E %
NEAR SPHERE PROPORTION; W:H ALMOST 1:1				
.5305751	96.80410	410.8948	89.10524	17.82
.6684828	153.6669	821.7895	178.2105	17.82
.8422355	243.9310	1643.579	356.4209	17.82
1.061150	387.2164	3287.158	712.8419	17.82
1.214714	507.3970	4930.737	1069.263	17.82
1.336966	614.6677	6574.316	1425.684	17.82
1.440202	713.2587	8217.895	1782.105	17.82
1.530444	805.4425	9861.474	2138.526	17.82
1.648620	934.6333	12326.84	2673.157	17.82
1.814541	1132.228	16435.79	3564.209	17.82
1.954655	1313.834	20544.74	4455.262	17.82
ASPECT RATIO = 1:1.2				
.5636324	97.39300	439.1508	60.84921	12.17
.7101323	154.6017	878.3016	121.6984	12.17
.8947107	245.4150	1756.603	243.3968	12.17
1.127265	389.5720	3513.206	486.7937	12.17
1.290396	510.4837	5269.809	730.1905	12.17
1.420265	618.4070	7026.413	973.5874	12.17
1.529934	717.5977	8783.016	1216.984	12.17
1.625797	810.3424	10539.62	1460.381	12.17
1.751337	940.3191	13174.52	1825.476	12.17
1.927596	1139.115	17566.03	2433.968	12.17
2.076439	1321.826	21957.54	3042.460	12.17
ASPECT RATIO = 1:1.4				
.5933508	98.85991	469.2689	30.73113	6.15
.7475752	156.9303	938.5377	61.46225	6.15
.9418857	249.1114	1877.075	122.9245	6.15
1.186702	395.4396	3754.151	245.8490	6.15
1.358434	518.1725	5631.226	368.7735	6.15
1.495150	627.7213	7508.302	491.6980	6.15
1.610602	728.4061	9385.377	614.6225	6.15
1.711520	822.5476	11262.45	737.5471	6.15
1.843679	954.4820	14078.07	921.9338	6.15
2.029231	1156.273	18770.75	1229.245	6.15
2.185923	1341.735	23463.44	1536.556	6.15
ASPECT RATIO = 1:1.6				
.6203577	100.9023	500.7641	**-.764139**	**-.15**
.7816017	160.1724	1001.528	**-1.52828**	**-.15**
.9847565	254.2578	2003.057	**-3.05655**	**-.15**
1.240715	403.6092	4006.113	**-6.11311**	**-.15**
1.420265	528.8776	6009.170	**-9.16966**	**-.15**
1.563203	640.6896	8012.226	**-12.2262**	**-.15**
1.683910	743.4545	10015.28	**-15.2828**	**-.15**
1.789421	839.5409	12018.34	**-18.3393**	**-.15**
1.927596	974.2009	15022.92	**-22.9242**	**-.15**
2.121594	1180.160	20030.57	**-30.5655**	**-.15**
2.285417	1369.455	25038.21	**-38.2069**	**-.15**
ASPECT RATIO = 1:1.8				
.6451980	103.3362	533.3787	**-33.3787**	**-6.68**
.8128986	164.0360	1066.757	**-66.7574**	**-6.68**
1.024188	260.3910	2133.515	**-133.515**	**-6.68**
1.290396	413.3449	4267.029	**-267.029**	**-6.68**
1.477135	541.6351	6400.544	**-400.544**	**-6.68**
1.625797	656.1442	8534.059	**-534.059**	**-6.68**
1.751337	761.3879	10667.57	**-667.574**	**-6.68**
1.861073	859.7921	12801.09	**-801.088**	**-6.68**
2.004780	997.7004	16001.36	**-1001.36**	**-6.68**
2.206546	1208.628	21335.15	**-1335.15**	**-6.68**
2.376930	1402.488	26668.93	**-1668.93**	**-6.68**

Spreadsheet to Evaluate the Properties of an Ellipsoidal Buoy

displaced volume Vb lb	aspect ratio a	Diameter W ft	Height H ft	major semi-axis w ft	minor semi-axis b ft	frontal area Af sq ft	t-1	eccentricity e	t-2	Surface Area As sq ft	Empirical eqn area As sq ft	Working depth assign ft	material allowable stress Sa psi
ASPECT RATIO = 1:2.0													
500	2	3.096921	1.548461	1.548461	.7742303	3.766345	15.06538	.8660254	5.727451	20.79283	19.58500	2000	24000
1000	2	3.901876	1.950938	1.950938	.9754690	5.978701	23.91480	.8660254	9.091762	33.00657	31.08924	2000	24000
2000	2	4.916056	2.458028	2.458028	1.229014	9.490596	37.96238	.8660254	14.43227	52.39466	49.35110	2000	24000
4000	2	6.193842	3.096921	3.096921	1.548461	15.06538	60.26153	.8660254	22.90981	83.17133	78.33999	2000	24000
6000	2	7.090179	3.545090	3.545090	1.772545	19.74124	78.96494	.8660254	30.02034	108.9853	102.6544	2000	24000
8000	2	7.803752	3.901876	3.901876	1.950938	23.91480	95.65921	.8660254	36.36705	132.0263	124.3570	2000	24000
10000	2	8.406337	4.203169	4.203169	2.101584	27.75067	111.0027	.8660254	42.20022	153.2029	144.3035	2000	24000
12000	2	8.933066	4.466533	4.466533	2.233267	31.33726	125.3490	.8660254	47.65432	173.0033	162.9537	2000	24000
15000	2	9.622854	4.811427	4.811427	2.405713	36.36367	145.4547	.8660254	55.29794	200.7526	189.0911	2000	24000
20000	2	10.59132	5.295661	5.295661	2.647830	44.05144	176.2058	.8660254	66.38868	243.1945	229.0675	2000	24000
25000	2	11.40915	5.704577	5.704577	2.852289	51.11717	204.4687	.8660254	77.73348	282.2022	265.8093	2000	24000
ASPECT RATIO = 1:2.2													
500	2.2	3.196890	1.453132	1.598445	.7265659	3.648569	16.05370	.8907235	5.307975	21.36168	18.97256	2000	24000
1000	2.2	4.027829	1.830831	2.013915	.9154157	5.791743	25.48367	.8907235	8.425886	33.90955	30.11706	2000	24000
2000	2.2	5.074747	2.306703	2.537373	1.153351	9.193818	40.45280	.8907235	13.37526	53.82806	47.80786	2000	24000
4000	2.2	6.393780	2.906264	3.196890	1.4531[illegible]	14.59428	64.21482	.8907235	21.23190	85.44672	75.89024	2000	24000
6000	2.2	7.319051	3.326841	3.659526	1.663421	19.12391	84.14522	.8907235	27.82166	111.9669	99.44435	2000	24000
8000	2.2	8.055658	3.661663	4.027829	1.830831	23.16697	101.9347	.8907235	33.70354	135.6382	120.4682	2000	24000
10000	2.2	8.677695	3.944407	4.338847	1.972203	26.88289	118.2847	.8907235	39.10950	157.3942	139.7910	2000	24000
12000	2.2	9.221427	4.191558	4.610713	2.095779	30.35732	133.5722	.8907235	44.16413	177.7363	157.8581	2000	24000
15000	2.2	9.933481	4.515218	4.966740	2.257609	35.22655	154.9968	.8907235	51.24794	206.2448	183.1781	2000	24000
20000	2.2	10.93321	4.969641	5.466605	2.484820	42.67392	187.7653	.8907235	62.08246	249.8477	221.9044	2000	24000
25000	2.2	11.77744	5.353383	5.888722	2.676692	49.51870	217.8823	.8907235	72.04031	289.9226	257.4973	2000	24000
ASPECT RATIO = 1:2.4													
500	2.4	3.290970	1.371237	1.645485	.6856187	3.544267	17.01248	.9090593	4.945272	21.95775	18.43019	2000	24000
1000	2.4	4.146362	1.727651	2.073181	.8638254	5.626173	27.00563	.9090593	7.850131	34.85576	29.25610	2000	24000
2000	2.4	5.224089	2.176704	2.612044	1.088352	8.930993	42.86876	.9090593	12.46131	55.33007	46.44116	2000	24000
4000	2.4	6.581939	2.742475	3.290970	1.371237	14.17707	68.04992	.9090593	19.78109	87.83101	73.72075	2000	24000
6000	2.4	7.534440	3.139350	3.767220	1.569675	18.57721	89.17062	.9090593	25.92056	115.0912	96.60151	2000	24000
8000	2.4	8.292724	3.455302	4.146362	1.727651	22.50469	108.0225	.9090593	31.40052	139.4230	117.0244	2000	24000
10000	2.4	8.933066	3.722111	4.466533	1.861055	26.11438	125.3490	.9090593	36.43708	161.7861	135.7948	2000	24000
12000	2.4	9.492799	3.955333	4.746400	1.977667	29.48949	141.5495	.9090593	41.14633	182.6959	153.3453	2000	24000
15000	2.4	10.22581	4.260753	5.112904	2.130377	34.21952	164.2537	.9090593	47.74608	211.9998	177.9415	2000	24000
20000	2.4	11.25496	4.689566	5.627479	2.344783	41.45400	198.9792	.9090593	57.84026	256.8194	215.5608	2000	24000
25000	2.4	12.12404	5.051682	6.062018	2.525841	48.10310	230.8949	.9090593	67.11767	298.0126	250.1361	2000	24000
ASPECT RATIO = 1:2.6													
500	2.6	3.379958	1.299984	1.689979	.6499918	3.450953	17.94496	.9230769	4.628412	22.57337	17.94496	2000	24000
1000	2.6	4.258480	1.637877	2.129240	.8189384	5.478046	28.48584	.9230769	7.347146	35.83299	28.48584	2000	24000
2000	2.6	5.365348	2.063595	2.682674	1.031798	8.695857	45.21845	.9230769	11.66287	56.88132	45.21845	2000	24000
4000	2.6	6.759915	2.599967	3.379958	1.299984	13.80381	71.77982	.9230769	18.51365	90.29347	71.77982	2000	24000
6000	2.6	7.738171	2.976220	3.869086	1.488110	18.08811	94.05817	.9230769	24.25974	118.3179	94.05817	2000	24000
8000	2.6	8.516959	3.275754	4.258480	1.637877	21.91219	113.9434	.9230769	29.38858	143.3319	113.9434	2000	24000
10000	2.6	9.174616	3.528699	4.587308	1.764349	25.42684	132.2196	.9230769	34.10243	166.3220	132.2196	2000	24000
12000	2.6	9.749485	3.749802	4.874742	1.874901	28.71309	149.3080	.9230769	38.50994	187.8180	149.3080	2000	24000
15000	2.6	10.50231	4.039352	5.251157	2.019676	33.31858	173.2566	.9230769	44.68683	217.9435	173.2566	2000	24000
20000	2.6	11.55929	4.445882	5.779646	2.222941	40.36259	209.8855	.9230769	54.13424	264.0197	209.8855	2000	24000
25000	2.6	12.45187	4.789181	6.225935	2.394590	46.83664	243.5505	.9230769	62.81722	306.3677	243.5505	2000	24000

Spreadsheet to Evaluate the Properties of an Ellipsoidal Buoy

Material thick-ness t in	1/8-In Thin Shell Weight Wbt lb	Buoy Weight Wb lb	Net Buoyancy Bn lb	Efficiency E %
ASPECT RATIO = 1:2.0				
.6682601	106.0435	566.9168	-66.9168	-13.38
.8419550	168.3335	1133.834	-133.834	-13.38
1.060797	267.2128	2267.667	-267.667	-13.38
1.336520	424.1738	4535.335	-535.335	-13.38
1.529934	555.8249	6803.002	-803.002	-13.38
1.683910	673.3339	9070.670	-1070.67	-13.38
1.813937	781.3348	11338.34	-1338.34	-13.38
1.927596	882.3171	13606.00	-1606.00	-13.38
2.076439	1023.838	17007.51	-2007.51	-13.38
2.285417	1240.292	22676.67	-2676.67	-13.38
2.461891	1439.231	28345.84	-3345.84	-13.38
ASPECT RATIO = 1:2.2				
.6898316	108.9446	601.2273	-101.227	-20.25
.8691334	172.9387	1202.455	-202.455	-20.25
1.095039	274.5231	2404.909	-404.909	-20.25
1.379663	435.7783	4809.818	-809.818	-20.25
1.579320	571.0311	7214.727	-1214.73	-20.25
1.738267	691.7549	9619.636	-1619.64	-20.25
1.872491	807.7104	12024.55	-2024.55	-20.25
1.989819	906.4553	14429.45	-2429.45	-20.25
2.143467	1051.848	18036.82	-3036.82	-20.25
2.359191	1274.223	24049.09	-4049.09	-20.25
2.541361	1478.605	30061.36	-5061.36	-20.25
ASPECT RATIO = 1:2.4				
.7101323	111.9845	636.1907	-136.191	-27.24
.8947107	177.7644	1272.381	-272.381	-27.24
1.127265	282.1834	2544.763	-544.763	-27.24
1.420265	447.9382	5089.526	-1089.53	-27.24
1.625797	586.9650	7634.289	-1634.29	-27.24
1.789421	711.0575	10179.05	-2179.05	-27.24
1.927596	825.1092	12723.81	-2723.81	-27.24
2.048376	931.7489	15268.58	-3268.58	-27.24
2.206546	1081.199	19085.72	-4085.72	-27.24
2.428618	1309.779	25447.63	-5447.63	-27.24
2.616150	1519.864	31809.54	-6809.54	-27.24
ASPECT RATIO = 1:2.6				
.7293343	115.1242	671.7121	-171.712	-34.34
.9189037	182.7482	1343.424	-343.424	-34.34
1.157746	290.0947	2686.848	-686.848	-34.34
1.458669	460.4967	5373.697	-1373.70	-34.34
1.669759	603.4214	8060.545	-2060.54	-34.34
1.837807	730.9929	10747.39	-2747.39	-34.34
1.979718	848.2422	13434.24	-3434.24	-34.34
2.103764	957.8717	16121.09	-4121.09	-34.34
2.266211	1111.512	20151.36	-5151.36	-34.34
2.494288	1346.501	26868.48	-6868.48	-34.34
2.686891	1562.475	33585.60	-8585.60	-34.34

APPENDIX D

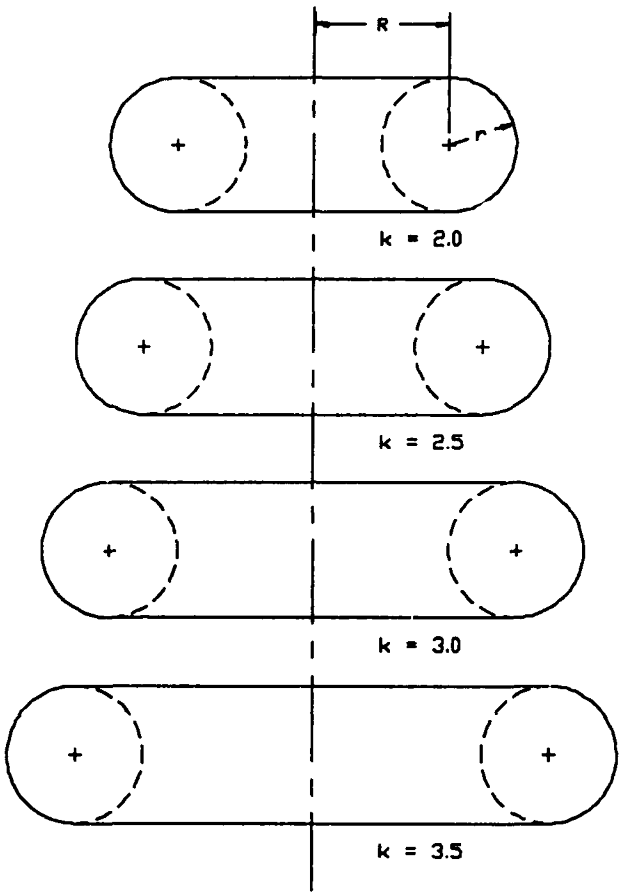
CALCULATIONS OF THE PARAMETERS FOR TORROIDAL SUBSURFACE BUOYS

Listing of Spreadsheet Calculation Lines for Torroidal Buoy
Refer to Figure 16 for Derivation Information

SuperCalc ver. 2.1

COLUMN	SYMBOL	CALCULATION	FUNCTION	UNITS	EQUATION
*	K = R / r		Rotation ratio	-	assign
A	Dg =	200	Gross Displacement	lb.	input value
B	Vb =	A9/64.3	Volume Buoy	Cu ft	Dg / d
C	k =	2.0	Aspect ratio	-	assign
D	r =	(B9/4/C9/PI^2)^(1/3)	Section Radius	ft	$(Vb / (4\ Pi^2))^{1/3}$
E	R =	2*C9	Radius of Rotation	ft	k r
F	Af =	4*PI^2*D9*C9	Frontal Area	sq ft	$4\ Pi\ r^2\ R$
G	As =	4*PI^2*D9*C9	Surface Area	sq ft	$4\ Pi^2\ R\ r$
H	Ds =	2000	Working Depth	ft	Assign
I	Sa =	24	Allowable Stress	ksi	Assign
J	t =	G9*.446*C9*12/2/H9/1000	Wall thickness	in	.446 Ds r 12 / (2 Sa 1000)
K	Wb =	F9*I9*40.8	Shell Weight	lb	As t 40.8
L	Bb =	A9-J9	Net Buoyancy	lb	Dg - Wb
M	E =	100-(100*(a9-k9)/a9)	Efficiency	%	$100 - 100\ (D_g - B_b) / D_g$

Torroidal Buoy Profiles for The Four Calculated Cases



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Spreadsheet to Evaluate the Properties of a Torroidal Buoy Structure

Displ Water pounds	Volume cu ft	Aspect ratio -	radius section ft	Radius of rotation ft	Frontal area sq ft	Surface area sq ft	Service depth ft	Material stress ksi	Material thickness in	Material Weight lb	Net Buoyancy lb	Efficiency %
entry	Vb	R/r	r	R	Af	As	Ds	Sa	t	Wb	Bb	E
Set k = 2.0												
200	3.110420	2	.4286996	.8573992	14.51095	14.51095	2000	24	.0956000	56.59969	143.4003	71.70
500	7.776050	2	.5818349	1.163670	26.72940	26.72940	2000	24	.1297492	141.4992	358.5008	71.70
1000	15.55210	2	.7330660	1.466132	42.43028	42.43028	2000	24	.1634737	282.9984	717.0016	71.70
1200	18.66252	2	.7789989	1.557998	47.91411	47.91411	2000	24	.1737168	339.5981	860.4019	71.70
1400	21.77294	2	.8200729	1.640146	53.10001	53.10001	2000	24	.1828762	396.1978	1003.802	71.70
1600	24.88336	2	.8573992	1.714798	58.04381	58.04381	2000	24	.1912000	452.7975	1147.202	71.70
2000	31.10420	2	.9236053	1.847211	67.35388	67.35388	2000	24	.2059640	565.9969	1434.003	71.70
5000	77.76050	2	1.253525	2.507051	124.0669	124.0669	2000	24	.2795361	1414.992	3585.008	71.70
8000	124.4168	2	1.466132	2.932264	169.7211	169.7211	2000	24	.3269475	2263.988	5736.012	71.70
10000	155.5210	2	1.579343	3.158686	196.9439	196.9439	2000	24	.3521935	2829.984	7170.016	71.70
12000	186.6252	2	1.678302	3.356605	222.3976	222.3976	2000	24	.3742614	3395.981	8604.019	71.70
16000	248.8336	2	1.847211	3.694421	269.4155	269.4155	2000	24	.4119280	4527.975	11472.02	71.70
20000	311.0420	2	1.989847	3.979695	312.6290	312.6290	2000	24	.4437360	5659.969	14340.03	71.70
25000	388.8025	2	2.143498	4.286996	362.7738	362.7738	2000	24	.4780001	7074.961	17925.04	71.70
Set k = 2.5												
200	3.110420	2.5	.3979695	.7959389	12.50516	12.50516	2000	24	.0887472	45.27975	154.7202	77.36
500	7.776050	2.5	.5401277	1.080255	23.03470	23.03470	2000	24	.1204485	113.1994	386.8006	77.36
1000	15.55210	2.5	.6805182	1.361036	36.56531	36.56531	2000	24	.1517556	226.3988	773.6012	77.36
1200	18.66252	2.5	.7231585	1.446317	41.29113	41.29113	2000	24	.1612644	271.6785	928.3215	77.36
1400	21.77294	2.5	.7612882	1.522576	45.76020	45.76020	2000	24	.1697673	316.9583	1083.042	77.36
1600	24.88336	2.5	.7959389	1.591878	50.02064	50.02064	2000	24	.1774944	362.2380	1237.762	77.36
2000	31.10420	2.5	.8573992	1.714798	58.04381	58.04381	2000	24	.1912000	452.7975	1547.202	77.36
5000	77.76050	2.5	1.163670	2.327340	106.9176	106.9176	2000	24	.2594984	1131.994	3868.006	77.36
8000	124.4168	2.5	1.361036	2.722073	146.2612	146.2612	2000	24	.3035111	1811.190	6188.810	77.36
10000	155.5210	2.5	1.466132	2.932264	169.7211	169.7211	2000	24	.3269475	2263.988	7736.012	77.36
12000	186.6252	2.5	1.557998	3.115996	191.6564	191.6564	2000	24	.3474335	2716.785	9283.215	77.36
16000	248.8336	2.5	1.714798	3.429597	232.1752	232.1752	2000	24	.3824001	3622.380	12377.62	77.36
20000	311.0420	2.5	1.847211	3.694421	269.4155	269.4155	2000	24	.4119280	4527.975	15472.02	77.36
25000	388.8025	2.5	1.989847	3.979695	312.6290	312.6290	2000	24	.4437360	5659.969	19340.03	77.36
Set k = 3.0												
200	3.110420	3	.3745036	.7490072	11.07393	11.07393	2000	24	.0835143	37.73313	162.2669	81.13
500	7.776050	3	.5082796	1.016559	20.39835	20.39835	2000	24	.1133464	94.33281	405.6672	81.13
1000	15.55210	3	.6403922	1.280784	32.38037	32.38037	2000	24	.1428075	188.6656	811.3344	81.13
1200	18.66252	3	.6805182	1.361036	36.56531	36.56531	2000	24	.1517556	226.3988	973.6012	81.13
1400	21.77294	3	.7163996	1.432799	40.52289	40.52289	2000	24	.1597571	264.1319	1135.868	81.13
1600	24.88336	3	.7490072	1.498014	44.29572	44.29572	2000	24	.1670286	301.8650	1298.135	81.13
2000	31.10420	3	.8068436	1.613687	51.40063	51.40063	2000	24	.1799261	377.3313	1622.669	81.13
5000	77.76050	3	1.095055	2.190110	94.68076	94.68076	2000	24	.2441973	943.3281	4056.672	81.13
8000	124.4168	3	1.280784	2.561569	129.5215	129.5215	2000	24	.2856149	1509.325	6490.675	81.13
10000	155.5210	3	1.379683	2.759366	150.2963	150.2963	2000	24	.3076693	1886.656	8113.344	81.13
12000	186.6252	3	1.466132	2.932264	169.7211	169.7211	2000	24	.3269475	2263.988	9736.012	81.13
16000	248.8336	3	1.613687	3.227374	205.6025	205.6025	2000	24	.3598522	3018.650	12981.35	81.13
20000	311.0420	3	1.738292	3.476584	238.5806	238.5806	2000	24	.3876391	3773.313	16226.69	81.13
25000	388.8025	3	1.872518	3.745036	276.8482	276.8482	2000	24	.4175713	4716.641	20283.36	81.13
Set k = 3.5												
200	3.110420	3.5	.3557463	.7114926	9.992417	9.992417	2000	24	.0793314	32.34268	167.6573	83.83
500	7.776050	3.5	.4828220	.9656441	18.40619	18.40619	2000	24	.1076693	80.85670	419.1433	83.93
1000	15.55210	3.5	.6083176	1.216635	29.21801	29.21801	2000	24	.1356548	161.7134	838.2866	83.83
1200	18.66252	3.5	.6464340	1.292868	32.99423	32.99423	2000	24	.1441548	194.0561	1005.944	83.83
1400	21.77294	3.5	.6805182	1.361036	36.56531	36.56531	2000	24	.1517556	226.3988	1173.601	83.83
1600	24.88336	3.5	.7114926	1.422985	39.96967	39.96967	2000	24	.1586629	258.7414	1341.259	83.83
2000	31.10420	3.5	.7664322	1.532864	46.38069	46.38069	2000	24	.1709144	323.4268	1676.573	83.83
5000	77.76050	3.5	1.040209	2.080417	85.43397	85.43397	2000	24	.2319665	808.5670	4191.433	83.83
8000	124.4168	3.5	1.216635	2.433271	116.8720	116.8720	2000	24	.2713097	1293.707	6706.293	83.83
10000	155.5210	3.5	1.310581	2.621161	135.6180	135.6180	2000	24	.2922595	1617.134	8382.866	83.83
12000	186.6252	3.5	1.392700	2.785399	153.1457	153.1457	2000	24	.3105720	1940.561	10059.44	83.83
16000	248.8336	3.5	1.532864	3.065729	185.5228	185.5228	2000	24	.3418288	2587.414	13412.59	83.83
20000	311.0420	3.5	1.651228	3.302456	215.2801	215.2801	2000	24	.3682239	3234.268	16765.73	83.83
25000	388.8025	3.5	1.778732	3.557463	249.8104	249.8104	2000	24	.3966571	4042.835	20957.17	83.83

APPENDIX E

CALCULATIONS OF THE PARAMETERS FOR TOROSPHERICAL SHELL BUOYS

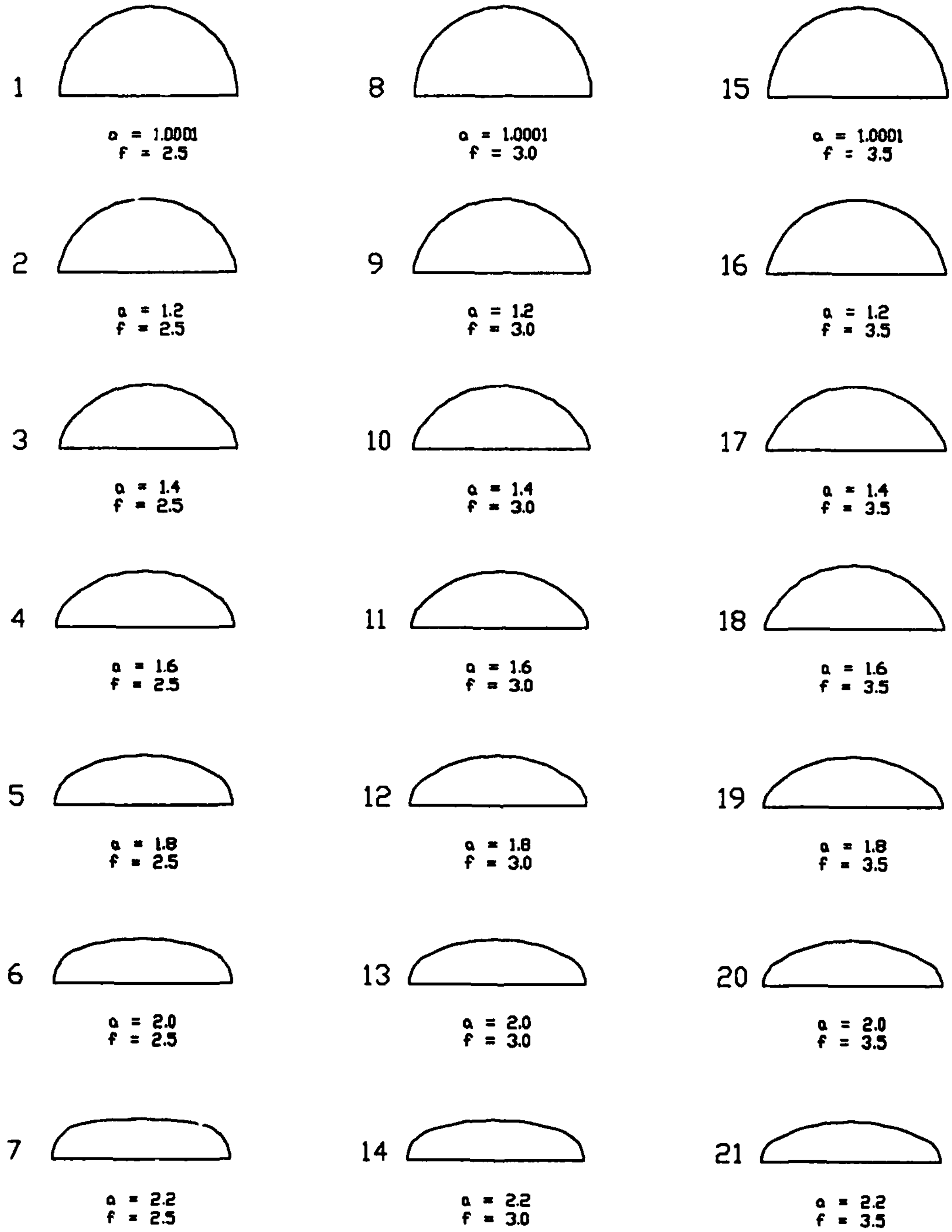
TWENTY-ONE OF PROPORTION VARIATION
IN
THREE PARTS
FOR EIGHT SELECTED SIZES OF BUOY

Calculations for the Parameters of Buoys Constructed as a Torospherical Shell

SuperCalc ver. 2.1

COL	SYMB	EXPRESSION	DESCRIPTION	UNITS	EQUATION
B	W	= 1	Buoy Major Semi-axis	ft	assigned
C	a	= 1	Buoy Height : Diameter Ratio	-	assigned
D	f	= 2.5	Buoy Flange : Diameter Ratio	-	assigned
E	H	= B12/C12	Crown Height; Minor Semiaxis	ft	W / a
F	F	= 1/D12	Flange factor	-	1 / f
G	r	= B12*F12	Flange Radius	ft	F W
H	j	= B12/C12-G12	Crown Bulge	ft	(W / a) - r
I	w	= B12-F12*B12	Flange Radius Offset	ft	W - F W
J	ψ_r	= ATAN(H12/I12)	Crown Bulge Angle	radians	atan(j / w)
K	ψ_d	= J12*B5	"	degrees	$180\ \psi_r / \pi$
L	ϕ_r	= 2*J12	Crown Arc Half Angle	radians	$2\ \psi_r$
M	ϕ_d	= L12*B5	"	degrees	$180\ \phi_r / \pi$
N	C	= B12/C12-(F12*B12*COS(L12))	Crown Height	ft	$W / a (F W \cos\phi_r$
O	θ_r	= 90/B5-L12	Flange Arc Angle	radians	$\pi / 2 - \phi_r$
P	θ_d	= O12*B5	"	degrees	$180\ \theta_r / \pi$
Q	R	= G12+(I12/SIN(L12))	Crown Radius	ft	$r + (w / \sin\phi_r)$
R	V_c	= PI/3*(N12^2)*(3*Q12-N12)	Crown Volume	cu ft	$\pi C^2 (3 R - C) / 3$
S	V_f	= PI*((B12^2*G12*SIN(O12))-(G12*SIN(O12))^3/3)	Flange Volume	cu ft	$\pi (W^2 r \sin\theta - (r \sin\theta)^3 / 3)$
T	V_e	= R12+S12	Volume of Bell	cu ft	$V_c + V_f$
U	V_b	= 2*T12	Volume of Buoy	cu ft	$2 V_e$
V	l_1	= 2*PI*Q12*M12/360	Surface Profile Calc Parameter	ft	$2 \pi R \phi_d / 360$
W	c_1	= 2*Q12*SIN(L12/2)	"	ft	$2 R \sin(\phi_r / 2)$
X	d_1	= Q12*W12/V12	"	ft	$R c_1 / l_1$
Y	s_1	= X12*SIN(L12/2)	"	ft	$d_1 \sin(\phi_r / 2)$
Z	l_2	= 2*PI*G12*P12/360	"	ft	$2 \pi r \theta_r / 360$
AA	c_2	= 2*G12*SIN(O12/2)	"	ft	$2 r \sin(\theta_r / 2)$
AB	d_2	= G12*AA12/Z12	"	ft	$r c_2 / l_2$
AC	s_2	= AB12*COS(O12/2)+I12	"	ft	$d_2 \cos(\theta_r / 2) + w$
AD	X	= (V12*Y12+Z12*AC12)/(V12+Z12)	Surface Profile CG Radius	ft	$((l_1 s_1) + (l_2 s_2)) / (l_1 + l_2)$
AE	A_e	= 2*PI*AD12*(V12+Z12)	Surface Area of Head	sq ft	$2 \pi X (l_1 + l_2)$
AF	A_b	= 2*AE12	Surface Area of Buoy	sq ft	$2 A_e$
AG	d	= 2000	Working Depth	ft	assigned
AH	P	= AG12*.446	Working Pressure	psi	.446 d
AI	S_a	= 24	Material Allowable Stress	ksi	assigned
AJ	M	= (3+(q12/g13)^.5)/4	Knuckle Stress Factor	-	$(3+(R / r)^{1/2}) /4$
AK	t	= AH12*Q12*AJ12*12/(2*24000+892*(AJ12-.2))	Shell Material Thickness	in	$12 P R M / (2 S_a + (M - 0.2)$
AL	W_b	= AF12*40.8*AK12	Buoy Weight	lb	$40.8 A_b t$
AM	W_t	= AF12*40.8*.125	Thin Shell Weight	lb	$40.8 A_b 0.125$
AN	D_g	= U12*64.3	Gross Displacement	cu ft	$64.3 V_b$
AO	B	= AN12-AL12	Net Buoyancy	lb	$D_g - W_b$
AP	E	= 100-(100*(AN12-AO13)/AN13)	Efficiency	%	$100 - (100 (D_g - B) / D_g)$

Torospherical Profiles Twenty-one Shapes in Three Families



An AutoLisp Program Routine Created to Construct the Torospherical Outlines shown on the Previous Page is Reproduced Below.

```
(defun c:torodraw ()
; input data values
(setq   p1 (getpoint "\nPick a basepoint for the drawn shape: ")
      D (getreal "\nBuoy Diameter - 'D': ")
      A (getreal "\nHeight Ratio - 'a': ")
      F (getreal "\nFlange Ratio - 'f': ")
      R (getreal "\nCrown Radius - 'R': ")
); end setq

; calculate derived values
(setq           E (/ D 2)
      H (/ E A)
      S (/ E F)
      W (- E S)
      L (- R S)
      I (- R H)
      Theta (- (/ PI 2) (atan (/ w l)))
      x (* S (cos theta))
      y (* S (sin theta))
);end setq

; calculate construction points
(setq p1x (car p1)
      p1y (cadr p1)
      p2 (list (+ p1x E) p1y)
      p3 (list p1x (+ p1y H))
      p4 (list p1x (- p1y l))
      p5 (list (+ p1x W) p1y)
      p6 (list (+ p1x W x) (+ p1y y))
);end setq

; construct figure
(command "line" p1 p2 ""
       "arc" p2 "c" p5 p6 \r)
(command "arc" p6 "c" p4 p3 \r)
(command "mirror" "w" p3 p2 "" p1 p3 "n" \r
) ; end of drawing sequence

; install labels
(command "dtext" "c" (list p1x (- p1y 0.5)) 0.125 0 "A = !a" \r
       "F = !f" \r
);end text command
);end defun
```

Buoy Radius 57.29578 W Major 1/2 axis ft	Buoy crown height H Minor 1/2 axis ft	crown radius R calc ft	flange radius r calc ft	Total water displaced Dg cu ft	Final thick shell t inches	Net Buoyancy B pounds	Efficiency E %	Buoy thin shell weight Wt 1/8"plate pounds
CASE ONE: CROWN HEIGHT RATIO = 1:1 = SPHERICAL SHAPE								
1	1.00	1.00	.40	269.34	.29	120.40	44.70	64.08849
2	2.00	2.00	.80	2154.71	.58	963.22	44.70	256.3540
3	3.00	3.00	1.20	7272.16	.87	3250.87	44.70	576.7964
4	4.00	4.00	1.60	17237.71	1.16	7705.77	44.70	1025.416
5	5.00	5.00	2.00	33667.40	1.45	15050.34	44.70	1602.212
6	6.00	6.00	2.40	58177.27	1.74	26006.99	44.70	2307.186
7	7.00	7.00	2.80	92383.35	2.03	41298.13	44.70	3140.336
8	8.00	8.00	3.20	137901.68	2.32	61646.19	44.70	4101.663
CASE TWO: CROWN HEIGHT RATIO 1:1.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5								
1	.83	1.03	.40	211.59	.30	79.81	37.72	54.94395
2	1.67	2.06	.80	1692.70	.60	638.48	37.72	219.7758
4	3.33	4.13	1.60	13541.58	1.20	5107.80	37.72	879.1032
5	4.17	5.16	2.00	26448.40	1.50	9976.18	37.72	1373.599
6	5.00	6.19	2.40	45702.84	1.80	17238.83	37.72	1977.982
7	5.83	7.22	2.80	72574.41	2.10	27374.63	37.72	2692.254
8	6.67	8.26	3.20	108332.65	2.40	40862.42	37.72	3516.413
CASE THREE: CROWN HEIGHT RATIO 1:1.4, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5								
1	.71	1.13	.40	182.97	.33	50.67	27.69	50.38644
2	1.43	2.26	.80	1463.75	.66	405.34	27.69	201.5458
3	2.14	3.39	1.20	4940.14	.98	1368.02	27.69	453.4780
4	2.86	4.52	1.60	11709.97	1.31	3242.70	27.69	806.1830
5	3.57	5.65	2.00	22871.04	1.64	6333.40	27.69	1259.661
6	4.29	6.78	2.40	39521.15	1.97	10944.12	27.69	1813.912
7	5.00	7.91	2.80	62758.12	2.30	17378.86	27.69	2468.936
8	5.71	9.04	3.20	93679.76	2.63	25941.63	27.69	3224.732
CASE FOUR: CROWN HEIGHT RATIO 1:1.6, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5								
1	.63	1.31	.40	169.04	.38	22.42	13.26	48.07237
2	1.25	2.63	.80	1352.34	.76	179.32	13.26	192.2895
3	1.88	3.94	1.20	4564.16	1.14	605.21	13.26	432.6514
4	2.50	5.25	1.60	10818.75	1.53	1434.58	13.26	769.1580
5	3.13	6.56	2.00	21130.37	1.91	2801.91	13.26	1201.809
6	3.75	7.88	2.40	36513.28	2.29	4841.70	13.26	1730.605
7	4.38	9.19	2.80	57981.73	2.67	7688.43	13.26	2355.546
8	5.00	10.50	3.20	86549.99	3.05	11476.61	13.26	3076.632
CASE FIVE: CROWN HEIGHT RATIO 1:1.8, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5								
1	.56	1.63	.40	162.33	.47	-15.86	-9.77	46.89808
2	1.11	3.27	.80	1298.64	.95	-126.85	-9.77	187.5923
3	1.67	4.90	1.20	4382.91	1.42	-428.10	-9.77	422.0827
4	2.22	6.54	1.60	10389.12	1.90	-1014.76	-9.77	750.3693
5	2.78	8.17	2.00	20291.26	2.37	-1981.96	-9.77	1172.452
6	3.33	9.81	2.40	35063.29	2.85	-3424.82	-9.77	1688.331
7	3.89	11.44	2.80	55679.21	3.32	-5438.48	-9.77	2298.006
8	4.44	13.08	3.20	83113.00	3.80	-8118.09	-9.77	3001.477
CASE SIX: CROWN HEIGHT RATIO 1:2.0, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5								
1	.50	2.25	.40	158.78	.65	-83.41	-52.53	46.31802
2	1.00	4.50	.80	1270.21	1.31	-667.30	-52.53	185.2721
3	1.50	6.75	1.20	4286.97	1.96	-2252.12	-52.53	416.8622
4	2.00	9.00	1.60	10161.70	2.61	-5338.36	-52.53	741.0883
5	2.50	11.25	2.00	19847.07	3.27	-10426.49	-52.53	1157.950
6	3.00	13.50	2.40	34295.74	3.92	-18016.98	-52.53	1667.449
7	3.50	15.75	2.80	54460.37	4.58	-28610.30	-52.53	2269.583
8	4.00	18.00	3.20	81293.62	5.23	-42706.91	-52.53	2964.353
CASE SEVEN: CROWN HEIGHT RATIO 1:2.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5								
1	.45	3.73	.40	156.34	1.08	-242.57	-155.15	46.05388
2	.91	7.45	.80	1250.75	2.17	-1940.56	-155.15	184.2155
3	1.36	11.18	1.20	4221.28	3.25	-6549.38	-155.15	414.4849
4	1.82	14.91	1.60	10006.01	4.33	-15524.44	-155.15	736.8621
5	2.27	18.64	2.00	19542.98	5.41	-30321.18	-155.15	1151.347
6	2.73	22.36	2.40	33770.27	6.50	-52395.00	-155.15	1657.940
7	3.18	26.09	2.80	53625.94	7.58	-83201.32	-155.15	2256.640
8	3.64	29.82	3.20	80048.06	8.66	-124195.56	-155.15	2947.448

SUMMARY PAGE

Buoy Radius W Major 1/2 axis ft	crown height H Minor 1/2 axis ft	crown radius R calc ft	flange radius r calc ft	Total water displaced Dg cu ft	thick shell t inches	Net Buoyancy B pounds	Efficiency E %	Buoy thin shell weight Wt pounds
CASE EIGHT: CROWN HEIGHT RATIO 1:1, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0								
1	1.00	1.00	.33	269.34	.30	116.04	43.08	64.08849
2	2.00	2.00	.67	2154.71	.60	928.28	43.08	256.3540
3	3.00	3.00	1.00	7272.16	.90	3132.95	43.08	576.7964
4	4.00	4.00	1.33	17237.71	1.20	7426.24	43.08	1025.416
5	5.00	5.00	1.67	33667.40	1.50	14504.38	43.08	1602.212
6	6.00	6.00	2.00	58177.27	1.79	25063.57	43.08	2307.186
7	7.00	7.00	2.33	92383.35	2.09	39800.02	43.08	3140.336
8	8.00	8.00	2.67	137901.68	2.39	59409.94	43.08	4101.663
CASE NINE: CROWN HEIGHT RATIO 1:1.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0								
1	.83	1.03	.33	210.41	.31	75.73	35.99	54.77848
2	1.67	2.06	.67	1683.26	.61	605.87	35.99	219.1139
4	3.33	4.11	1.33	13466.07	1.23	4846.94	35.99	876.4558
5	4.17	5.14	1.67	26300.91	1.54	9466.68	35.99	1369.462
6	5.00	6.17	2.00	45447.98	1.84	16358.43	35.99	1972.025
7	5.83	7.19	2.33	72169.70	2.15	25976.58	35.99	2684.146
8	6.67	8.22	2.67	107728.53	2.46	38775.53	35.99	3505.823
CASE TEN: CROWN HEIGHT RATIO 1:1.4, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0								
1	.71	1.11	.33	178.80	.33	46.71	26.13	49.87355
2	1.43	2.21	.67	1430.37	.66	373.70	26.13	199.4942
3	2.14	3.32	1.00	4827.49	.99	1261.24	26.13	448.8619
4	2.86	4.43	1.33	11442.95	1.32	2989.62	26.13	797.9768
5	3.57	5.54	1.67	22349.50	1.66	5839.09	26.13	1246.839
6	4.29	6.64	2.00	38619.94	1.99	10089.95	26.13	1795.448
7	5.00	7.75	2.33	61327.04	2.32	16022.47	26.13	2443.804
8	5.71	8.86	2.67	91543.57	2.65	23916.93	26.13	3191.907
CASE ELEVEN: CROWN HEIGHT RATIO 1:1.6, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0								
1	.63	1.24	.33	161.03	.37	20.98	13.03	47.17456
2	1.25	2.48	.67	1288.26	.74	167.87	13.03	188.6983
3	1.88	3.72	1.00	4347.86	1.11	566.55	13.03	424.5711
4	2.50	4.96	1.33	10306.05	1.48	1342.94	13.03	754.7930
5	3.13	6.21	1.67	20129.00	1.86	2622.93	13.03	1179.364
6	3.75	7.45	2.00	34782.92	2.23	4532.43	13.03	1698.284
7	4.38	8.69	2.33	55233.98	2.60	7197.33	13.03	2311.554
8	5.00	9.93	2.67	82448.39	2.97	10743.53	13.03	3019.172
CASE TWELVE: CROWN HEIGHT RATIO 1:1.8, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0								
1	.56	1.44	.33	150.64	.43	**-7.08**	**-4.70**	45.64629
2	1.11	2.89	.67	1205.10	.86	**-56.64**	**-4.70**	182.5851
3	1.67	4.33	1.00	4067.22	1.30	**-191.15**	**-4.70**	410.8166
4	2.22	5.78	1.33	9640.82	1.73	**-453.11**	**-4.70**	730.3406
5	2.78	7.22	1.67	18829.73	2.16	**-884.97**	**-4.70**	1141.157
6	3.33	8.67	2.00	32537.77	2.59	**-1529.24**	**-4.70**	1643.266
7	3.89	10.11	2.33	51668.78	3.02	**-2428.37**	**-4.70**	2236.668
8	4.44	11.56	2.67	77126.57	3.46	**-3624.86**	**-4.70**	2921.362
CASE THIRTEEN: CROWN HEIGHT RATIO 1:2.0, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0								
1	.50	1.75	.33	144.19	.52	**-43.21**	**-29.96**	44.76708
2	1.00	3.50	.67	1153.55	1.05	**-345.66**	**-29.96**	179.0683
3	1.50	5.25	1.00	3893.22	1.57	**-1166.60**	**-29.96**	402.9037
4	2.00	7.00	1.33	9228.36	2.09	**-2765.27**	**-29.96**	716.2732
5	2.50	8.75	1.67	18024.15	2.62	**-5400.92**	**-29.96**	1119.177
6	3.00	10.50	2.00	31145.72	3.14	**-9332.78**	**-29.96**	1611.615
7	3.50	12.25	2.33	49458.26	3.66	**-14820.12**	**-29.96**	2193.587
8	4.00	14.00	2.67	73826.90	4.19	**-22122.16**	**-29.96**	2865.093
CASE FOURTEEN: CROWN HEIGHT RATIO 1:2.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0								
1	.45	2.23	.33	139.85	.67	**-95.96**	**-68.61**	44.26070
2	.91	4.45	.67	1118.84	1.33	**-767.66**	**-68.61**	177.0428
3	1.36	6.68	1.00	3776.07	2.00	**-2590.85**	**-68.61**	398.3463
4	1.82	8.91	1.33	8950.69	2.66	**-6141.27**	**-68.61**	708.1712
5	2.27	11.14	1.67	17481.82	3.33	**-11994.66**	**-68.61**	1106.516
6	2.73	13.36	2.00	30208.59	4.00	**-20726.77**	**-68.61**	1593.385
7	3.18	15.59	2.33	47970.12	4.66	**-32913.34**	**-68.61**	2168.774
8	3.64	17.82	2.67	71605.55	5.33	**-49130.12**	**-68.61**	2832.685

57.29578 W Major 1/2 axis ft	crown height H Minor 1/2 axis ft	crown radius R calc ft	crown volume Vc calc cu ft	Total water displaced Dg cu ft	thick shell t inches	Net buoyancy pounds	Efficiency E %	Buoy thin shell weight Wt pounds
CASE FIFTEEN: CROWN HEIGHT RATIO 1:1.0, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5								
1	1.00	1.00	2.09	269.34	.31	111.67	41.46	64.08849
2	2.00	2.00	16.76	2154.71	.62	893.39	41.46	256.3540
3	3.00	3.00	56.55	7272.16	.92	3015.19	41.46	576.7964
4	4.00	4.00	134.04	17237.71	1.23	7147.12	41.46	1025.416
5	5.00	5.00	261.80	33667.40	1.54	13959.21	41.46	1602.212
6	6.00	6.00	452.39	58177.27	1.85	24121.52	41.46	2307.186
7	7.00	7.00	718.38	92383.35	2.15	38304.08	41.46	3140.336
8	8.00	8.00	1072.33	137901.68	2.46	57176.93	41.46	4101.663
CASE SIXTEEN: CROWN HEIGHT RATIO 1:1.2, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5								
1	.83	1.03	1.40	209.74	.32	71.80	34.24	54.68038
2	1.67	2.05	11.19	1677.89	.63	574.43	34.24	218.7215
4	3.33	4.10	89.49	13423.11	1.26	4595.45	34.24	874.8861
5	4.17	5.13	174.79	26217.02	1.58	8975.49	34.24	1367.010
6	5.00	6.15	302.03	45303.00	1.89	15509.65	34.24	1968.494
7	5.83	7.18	479.62	71939.49	2.21	24628.76	34.24	2679.339
8	6.67	8.20	715.93	107384.90	2.52	36763.63	34.24	3499.545
CASE SEVENTEEN: CROWN HEIGHT RATIO 1:1.4, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5								
1	.71	1.10	.95	176.51	.34	42.94	24.33	49.56993
2	1.43	2.19	7.62	1412.05	.67	343.55	24.33	198.2797
3	2.14	3.29	25.72	4765.67	1.01	1159.49	24.33	446.1293
4	2.86	4.38	60.97	11296.41	1.35	2748.43	24.33	793.1188
5	3.57	5.48	119.08	22063.29	1.68	5368.02	24.33	1239.248
6	4.29	6.57	205.78	38125.37	2.02	9275.94	24.33	1784.517
7	5.00	7.67	326.77	60541.68	2.36	14729.85	24.33	2428.926
8	5.71	8.76	487.77	90371.25	2.69	21987.41	24.33	3172.475
CASE EIGHTEEN: CROWN HEIGHT RATIO 1:1.6, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5								
1	.63	1.21	.66	156.67	.37	18.15	11.59	46.63982
2	1.25	2.41	5.26	1253.37	.74	145.23	11.59	186.5593
3	1.88	3.62	17.75	4230.14	1.11	490.15	11.59	419.7584
4	2.50	4.83	42.07	10026.99	1.48	1161.85	11.59	746.2372
5	3.13	6.04	82.17	19583.97	1.86	2269.23	11.59	1165.996
6	3.75	7.24	141.98	33841.10	2.23	3921.23	11.59	1679.034
7	4.38	8.45	225.46	53738.42	2.60	6226.76	11.59	2285.351
8	5.00	9.66	336.55	80215.95	2.97	9294.76	11.59	2984.949
CASE NINETEEN: CROWN HEIGHT RATIO 1:1.8, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5								
1	.56	1.37	.46	144.17	.42	**-6.69**	**-4.64**	44.89254
2	1.11	2.73	3.66	1153.39	.84	**-53.52**	**-4.64**	179.5702
3	1.67	4.10	12.37	3892.70	1.26	**-180.63**	**-4.64**	404.0329
4	2.22	5.46	29.31	9227.14	1.68	**-428.16**	**-4.64**	718.2807
5	2.78	6.83	57.25	18021.75	2.10	**-836.25**	**-4.64**	1122.314
6	3.33	8.20	98.93	31141.58	2.52	**-1445.05**	**-4.64**	1616.131
7	3.89	9.56	157.10	49451.68	2.94	**-2294.68**	**-4.64**	2199.735
8	4.44	10.93	234.51	73817.09	3.36	**-3425.30**	**-4.64**	2873.123
CASE TWENTY: CROWN HEIGHT RATIO 1:2.0, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5								
1	.50	1.58	.32	135.87	.49	**-34.82**	**-25.63**	43.82061
2	1.00	3.17	2.57	1086.93	.97	**-278.59**	**-25.63**	175.2824
3	1.50	4.75	8.68	3668.39	1.46	**-940.24**	**-25.63**	394.3855
4	2.00	6.33	20.57	8695.43	1.95	**-2228.71**	**-25.63**	701.1297
5	2.50	7.92	40.17	16983.27	2.43	**-4352.95**	**-25.63**	1095.515
6	3.00	9.50	69.41	29347.09	2.92	**-7521.90**	**-25.63**	1577.542
7	3.50	11.08	110.22	46602.09	3.41	**-11944.49**	**-25.63**	2147.210
8	4.00	12.67	164.53	69563.46	3.90	**-17829.68**	**-25.63**	2804.519
CASE TWENTY ONE: CROWN HEIGHT RATIO 1:2.2, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5								
1	.45	1.88	.23	130.02	.58	**-69.67**	**-53.58**	43.15053
2	.91	3.76	1.81	1040.19	1.16	**-557.34**	**-53.58**	172.6021
3	1.36	5.64	6.10	3510.65	1.74	**-1881.01**	**-53.58**	388.3547
4	1.82	7.52	14.46	8321.55	2.31	**-4458.69**	**-53.58**	690.4084
5	2.27	9.41	28.24	16253.03	2.89	**-8708.38**	**-53.58**	1078.763
6	2.73	11.29	48.80	28085.23	3.47	**-15048.07**	**-53.58**	1553.419
7	3.18	13.17	77.49	44598.31	4.05	**-23895.78**	**-53.58**	2114.376
8	3.64	15.05	115.67	66572.40	4.63	**-35669.51**	**-53.58**	2761.634

Part 1 of 3

July 17, 1990

Calculate Torospherical Shape Dimensions to Match a Given Set of Input Dimensions.

57.29578 W Major 1/2 axis ft	height ratio a input -	flange ratio f input -	crown height H Minor 1/2 axis ft	inverse 1/f calc -	flange radius r calc ft	j calc ft	w calc ft	psi calc radians	psi degrees	crown 1/2 angle phi calc radians	phi degrees	Crown height c calc ft	flange arc theta calc radians
CASE ONE: CROWN HEIGHT RATIO = 1:1 = SPHERICAL SHAPE													
1	1	2.5	1	.4	.4	.6	.6	.7853982	45	1.570796	90	1	6.66e-16
2	1	2.5	2	.4	.8	1.2	1.2	.7853982	45	1.570796	90	2	6.66e-16
3	1	2.5	3	.4	1.2	1.8	1.8	.7853982	45	1.570796	90	3	6.66e-16
4	1	2.5	4	.4	1.6	2.4	2.4	.7853982	45	1.570796	90	4	6.66e-16
5	1	2.5	5	.4	2	3	3	.7853982	45	1.570796	90	5	6.66e-16
6	1	2.5	6	.4	2.4	3.6	3.6	.7853982	45	1.570796	90	6	6.66e-16
7	1	2.5	7	.4	2.8	4.2	4.2	.7853982	45	1.570796	90	7	6.66e-16
8	1	2.5	8	.4	3.2	4.8	4.8	.7853982	45	1.570796	90	8	6.66e-16
CASE TWO: CROWN HEIGHT RATIO 1:1.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5													
1	1.2	2.5	.8333333	.4	.4	.4333333	.6	.6254850	35.83765	1.250970	71.67531	.7075727	.3198262
2	1.2	2.5	1.666667	.4	.8	.8666667	1.2	.6254850	35.83765	1.250970	71.67531	1.415145	.3198262
4	1.2	2.5	3.333333	.4	1.6	1.733333	2.4	.6254850	35.83765	1.250970	71.67531	2.830291	.3198262
5	1.2	2.5	4.166667	.4	2	2.166667	3	.6254850	35.83765	1.250970	71.67531	3.537863	.3198262
6	1.2	2.5	5	.4	2.4	2.6	3.6	.6254850	35.83765	1.250970	71.67531	4.245436	.3198262
7	1.2	2.5	5.833333	.4	2.8	3.033333	4.2	.6254850	35.83765	1.250970	71.67531	4.953009	.3198262
8	1.2	2.5	6.666667	.4	3.2	3.466667	4.8	.6254850	35.83765	1.250970	71.67531	5.660581	.3198262
CASE THREE: CROWN HEIGHT RATIO 1:1.4, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5													
1	1.4	2.5	.7142857	.4	.4	.3142857	.6	.4825133	27.64598	.9650266	55.29195	.4865277	.6057697
2	1.4	2.5	1.428571	.4	.8	.6285714	1.2	.4825133	27.64598	.9650266	55.29195	.9730554	.6057697
3	1.4	2.5	2.142857	.4	1.2	.9428571	1.8	.4825133	27.64598	.9650266	55.29195	1.459583	.6057697
4	1.4	2.5	2.857143	.4	1.6	1.257143	2.4	.4825133	27.64598	.9650266	55.29195	1.946111	.6057697
5	1.4	2.5	3.571429	.4	2	1.571429	3	.4825133	27.64598	.9650266	55.29195	2.432639	.6057697
6	1.4	2.5	4.285714	.4	2.4	1.885714	3.6	.4825133	27.64598	.9650266	55.29195	2.919166	.6057697
7	1.4	2.5	5	.4	2.8	2.2	4.2	.4825133	27.64598	.9650266	55.29195	3.405694	.6057697
8	1.4	2.5	5.714286	.4	3.2	2.514286	4.8	.4825133	27.64598	.9650266	55.29195	3.892222	.6057697
CASE FOUR: CROWN HEIGHT RATIO 1:..6, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5													
1	1.6	2.5	.625	.4	.4	.225	.6	.3587707	20.55605	.7175413	41.11209	.3236301	.8532550
2	1.6	2.5	1.25	.4	.8	.45	1.2	.3587707	20.55605	.7175413	41.11209	.6472603	.8532550
3	1.6	2.5	1.875	.4	1.2	.675	1.8	.3587707	20.55605	.7175413	41.11209	.9708904	.8532550
4	1.6	2.5	2.5	.4	1.6	.9	2.4	.3587707	20.55605	.7175413	41.11209	1.294521	.8532550
5	1.6	2.5	3.125	.4	2	1.125	3	.3587707	20.55605	.7175413	41.11209	1.618151	.8532550
6	1.6	2.5	3.75	.4	2.4	1.35	3.6	.3587707	20.55605	.7175413	41.11209	1.941781	.8532550
7	1.6	2.5	4.375	.4	2.8	1.575	4.2	.3587707	20.55605	.7175413	41.11209	2.265411	.8532550
8	1.6	2.5	5	.4	3.2	1.8	4.8	.3587707	20.55605	.7175413	41.11209	2.589041	.8532550
CASE FIVE: CROWN HEIGHT RATIO 1:1.8, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5													
1	1.8	2.5	.5555556	.4	.4	.1555556	.6	.2536741	14.53446	.5073482	29.06891	.2059412	1.063448
2	1.8	2.5	1.111111	.4	.8	.3111111	1.2	.2536741	14.53446	.5073482	29.06891	.4118823	1.063448
3	1.8	2.5	1.666667	.4	1.2	.4666667	1.8	.2536741	14.53446	.5073482	29.06891	.6178235	1.063448
4	1.8	2.5	2.222222	.4	1.6	.6222222	2.4	.2536741	14.53446	.5073482	29.06891	.8237646	1.063448
5	1.8	2.5	2.777778	.4	2	.7777778	3	.2536741	14.53446	.5073482	29.06891	1.029706	1.063448
6	1.8	2.5	3.333333	.4	2.4	.9333333	3.6	.2536741	14.53446	.5073482	29.06891	1.235647	1.063448
7	1.8	2.5	3.888889	.4	2.8	1.088889	4.2	.2536741	14.53446	.5073482	29.06891	1.441588	1.063448
8	1.8	2.5	4.444444	.4	3.2	1.244444	4.8	.2536741	14.53446	.5073482	29.06891	1.647529	1.063448
CASE SIX: CROWN HEIGHT RATIO 1:2.0, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5													
1	2	2.5	.5	.4	.4	.1	.6	.1651487	9.462322	.3302974	18.92464	.1216216	1.240499
2	2	2.5	1	.4	.8	.2	1.2	.1651487	9.462322	.3302974	18.92464	.2432432	1.240499
3	2	2.5	1.5	.4	1.2	.3	1.8	.1651487	9.462322	.3302974	18.92464	.3648649	1.240499
4	2	2.5	2	.4	1.6	.4	2.4	.1651487	9.462322	.3302974	18.92464	.4864865	1.240499
5	2	2.5	2.5	.4	2	.5	3	.1651487	9.462322	.3302974	18.92464	.6081081	1.240499
6	2	2.5	3	.4	2.4	.6	3.6	.1651487	9.462322	.3302974	18.92464	.7297297	1.240499
7	2	2.5	3.5	.4	2.8	.7	4.2	.1651487	9.462322	.3302974	18.92464	.8513514	1.240499
8	2	2.5	4	.4	3.2	.8	4.8	.1651487	9.462322	.3302974	18.92464	.9729730	1.240499
CASE SEVEN: CROWN HEIGHT RATIO 1:2.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5													
1	2.2	2.5	.4545455	.4	.4	.0545455	.6	.0906599	5.194429	.1813198	10.38886	.0611028	1.389477
2	2.2	2.5	.9090909	.4	.8	.1090909	1.2	.0906599	5.194429	.1813198	10.38886	.1222057	1.389477
3	2.2	2.5	1.363636	.4	1.2	.1636364	1.8	.0906599	5.194429	.1813198	10.38886	.1833085	1.389477
4	2.2	2.5	1.818182	.4	1.6	.2181818	2.4	.0906599	5.194429	.1813198	10.38886	.2444113	1.389477
5	2.2	2.5	2.272727	.4	2	.2727273	3	.0906599	5.194429	.1813198	10.38886	.3055142	1.389477
6	2.2	2.5	2.727273	.4	2.4	.3272727	3.6	.0906599	5.194429	.1813198	10.38886	.3666170	1.389477
7	2.2	2.5	3.181818	.4	2.8	.3818182	4.2	.0906599	5.194429	.1813198	10.38886	.4277198	1.389477
8	2.2	2.5	3.636364	.4	3.2	.4363636	4.8	.0906599	5.194429	.1813198	10.38886	.4888227	1.389477

Calculate Torospherical Shape Dimensions to Match a Given Set of Input Dimensions.

theta	crown radius R	crown volume Vc	flange volume Vf	volume end bell Ve	volume buoy Vb	--------parameters to derive C.G. of section-------- l1	c1	d1	s1	l2	c2	d2	s2
	calc	calc	calc	calc	calc								
degrees	ft	cu ft	cu ft	cu ft	cu ft	ft	ft	ft	ft	ft	ft	ft	ft
CASE ONE: CROWN HEIGHT RATIO = 1:1 = SPHERICAL SHAPE (continued)													
3.82e-14	1	2.094395	0	2.094395	4.188790	1.570796	1.414214	.9003163	.6366198	2.66e-16	0	0	.6
3.82e-14	2	16.75516	0	16.75516	33.51032	3.141593	2.828427	1.800633	1.273240	5.33e-16	0	0	1.2
3.82e-14	3	56.54867	0	56.54867	113.0973	4.712389	4.242641	2.700949	1.909859	7.99e-16	0	0	1.8
3.82e-14	4	134.0413	0	134.0413	268.0826	6.283185	5.656854	3.601265	2.546479	1.07e-15	0	0	2.4
3.82e-14	5	261.7994	0	261.7994	523.5988	7.853982	7.071068	4.501582	3.183099	1.33e-15	0	0	3
3.82e-14	6	452.3893	0	452.3893	904.7787	9.424778	8.485281	5.401898	3.819719	1.60e-15	0	0	3.6
3.82e-14	7	718.3775	0	718.3775	1436.755	10.99557	9.899495	6.302214	4.456338	1.87e-15	0	0	4.2
3.82e-14	8	1072.330	0	1072.330	2144.661	12.56637	11.31371	7.202531	5.092958	2.13e-15	0	0	4.8
CASE TWO: CROWN HEIGHT RATIO 1:1.2, FLANGE TO MAJOR AXIS RATIO (W/r) 2.5 (continued)													
18.32469	1.032051	1.252307	.3930059	1.645313	3.290625	1.291065	1.208513	.9660603	.5656192	.1279305	.1273860	.3982974	.9932155
18.32469	2.064103	10.01845	3.144047	13.16250	26.32500	2.582131	2.417025	1.932121	1.131238	.2558610	.2547719	.7965947	1.986431
18.32469	4.128205	80.14764	25.15237	105.3000	210.6000	5.164261	4.834050	3.864241	2.262477	.5117220	.5095438	1.593189	3.972862
18.32469	5.160256	156.5383	49.12573	205.6641	411.3282	6.455326	6.042563	4.830302	2.828096	.6396525	.6369298	1.991487	4.966078
18.32469	6.192308	270.4983	84.88927	355.3875	710.7751	7.746392	7.251075	5.796362	3.393715	.7675830	.7643157	2.389784	5.959293
18.32469	7.224359	429.5412	134.8010	564.3422	1128.684	9.037457	8.459588	6.762422	3.959334	.8955135	.8917017	2.788082	6.952509
18.32469	8.256410	641.1811	201.2190	842.4001	1684.800	10.32852	9.668100	7.728483	4.524954	1.023444	1.019088	3.186379	7.945724
CASE THREE. CROWN HEIGHT RATIO 1:1.4, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5 (continued)													
34.70805	1.129870	.7196199	.7031506	1.422771	2.845541	1.090355	1.048535	1.086535	.5041599	.2423079	.2386200	.3939120	.9759812
34.70805	2.259740	5.756959	5.625205	11.38216	22.76433	2.180709	2.097071	2.173070	1.008320	.4846158	.4772400	.7878241	1.951962
34.70805	3.389610	19.42974	18.98507	38.41480	76.82961	3.271064	3.145606	3.259605	1.512480	.7269237	.7158600	1.181736	2.927943
34.70805	4.519481	46.05568	45.00164	91.05731	182.1146	4.361419	4.194141	4.346141	2.016640	.9692316	.9544800	1.575648	3.903925
34.70805	5.649351	89.95249	87.89383	177.8463	355.6926	5.451774	5.242676	5.432676	2.520799	1.211539	1.193100	1.969560	4.879906
34.70805	6.779221	155.4379	151.8805	307.3184	614.6369	6.542128	6.291212	6.519211	3.024959	1.453847	1.431720	2.363472	5.855887
34.70805	7.909091	246.8296	241.1807	488.0103	976.0206	7.632483	7.339747	7.605746	3.529119	1.696155	1.670340	2.757384	6.831868
34.70805	9.038961	368.4454	360.0131	728.4585	1456.917	8.722838	8.388282	8.692281	4.033279	1.938463	1.908960	3.151296	7.807849
CASE FOUR: CROWN HEIGHT RATIO 1:1.6, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5 (continued)													
48.88791	1.3125	.3963684	.9181179	1.314486	2.628973	.9417730	.9216990	1.284524	.4510265	.3413020	.3310424	.3879759	.9532002
48.88791	2.625	3.170947	7.344943	10.51589	21.03178	1.883546	1.843398	2.569048	.9020529	.6826040	.6620847	.7759518	1.906400
48.88791	3.9375	10.70195	24.78918	35.49113	70.98226	2.825319	2.765097	3.853572	1.353079	1.023906	.9931271	1.163928	2.859601
48.88791	5.25	25.36758	58.75955	84.12713	168.2543	3.767092	3.686796	5.138096	1.804106	1.365208	1.324169	1.551904	3.812801
48.88791	6.5625	49.54605	114.7647	164.3108	328.6216	4.708865	4.608495	6.422620	2.255132	1.706510	1.655212	1.939879	4.766001
48.88791	7.875	85.61558	198.3135	283.9290	567.8581	5.650638	5.530194	7.707144	2.706159	2.047812	1.986254	2.327855	5.719201
48.88791	9.1875	135.9544	314.9144	450.8688	901.7376	6.592411	6.451893	8.991668	3.157185	2.389114	2.317296	2.715831	6.672402
48.88791	10.5	202.9406	470.0764	673.0170	1346.034	7.534184	7.373592	10.27619	3.608212	2.730416	2.648339	3.103807	7.625602
CASE FIVE: CROWN HEIGHT RATIO 1:1.8, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5 (continued)													
60.93109	1.634921	.2086910	1.053596	1.262287	2.524573	.8294740	.8206064	1.617442	.4059168	.4253793	.4056161	.3814160	.9287555
60.93109	3.269841	1.669528	8.428765	10.09829	20.19659	1.658948	1.641213	3.234885	.8118336	.8507585	.8112322	.7628319	1.857511
60.93109	4.904762	5.634658	28.44708	34.08174	68.16348	2.488422	2.461819	4.852327	1.217750	1.276138	1.216848	1.144248	2.786266
60.93109	6.539683	13.35623	67.43012	80.78635	161.5727	3.317896	3.282426	6.469769	1.623667	1.701517	1.622464	1.525664	3.715022
60.93109	8.174603	26.08638	131.6995	157.7858	315.5717	4.147370	4.103032	8.087211	2.029584	2.126896	2.028081	1.907080	4.643777
60.93109	9.809524	45.07726	227.5767	272.6539	545.3079	4.976844	4.923639	9.704654	2.435501	2.552276	2.433697	2.288496	5.572533
60.93109	11.44444	71.58103	361.3833	432.9643	865.9287	5.806318	5.744245	11.32210	2.841418	2.977655	2.839313	2.669912	6.501288
60.93109	13.07937	106.8498	539.4410	646.2908	1292.582	6.635792	6.564851	12.93954	3.247334	3.403034	3.244929	3.051328	7.430044
CASE SIX: CROWN HEIGHT RATIO 1:2.0, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5 (continued)													
71.07536	2.25	.1026733	1.131981	1.234655	2.469309	.7431690	.7397954	2.239786	.3682186	.4961996	.4649906	.3748415	.9050211
71.07536	4.5	.8213863	9.055851	9.877238	19.75448	1.486338	1.479591	4.479572	.7364372	.9923992	.9299811	.7496831	1.810042
71.07536	6.75	2.772179	30.56350	33.33568	66.67135	2.229507	2.219386	6.719358	1.104656	1.488599	1.394972	1.124525	2.715063
71.07536	9	6.571091	72.44681	79.01790	158.0358	2.972676	2.959182	8.959145	1.472874	1.984798	1.859962	1.499366	3.620084
71.07536	11.25	12.83416	141.4977	154.3318	308.6637	3.715845	3.698977	11.19893	1.841093	2.480998	2.324953	1.874208	4.525106
71.07536	13.5	22.17743	244.5080	266.6854	533.3708	4.459014	4.438773	13.43872	2.209311	2.977198	2.789943	2.249049	5.430127
71.07536	15.75	35.21694	388.2696	423.4866	846.9731	5.202183	5.178568	15.67850	2.577530	3.473397	3.254934	2.623891	6.335148
71.07536	18	52.56873	579.5745	632.1432	1264.286	5.945352	5.918364	17.91829	2.945749	3.969597	3.719924	2.998732	7.240169
CASE SEVEN: CROWN HEIGHT RATIO 1:2.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5 (continued)													
79.61114	3.727273	.0434794	1.172258	1.215738	2.431475	.6758283	.6749028	3.722169	.3369893	.5557906	.5121475	.3685903	.8831589
79.61114	7.454545	.3478356	9.378065	9.725901	19.45180	1.351657	1.349806	7.444338	.6739787	1.111581	1.024295	.7371805	1.766318
79.61114	11.18182	1.173945	31.65097	32.82492	65.64983	2.027485	2.024709	11.16651	1.010968	1.667372	1.536443	1.105771	2.649477
79.61114	14.90909	2.782685	75.02452	77.80721	155.6144	2.703313	2.699611	14.88868	1.347957	2.223162	2.048590	1.474361	3.532636
79.61114	18.63636	5.434931	146.5323	151.9672	303.9344	3.379141	3.374514	18.61084	1.684947	2.778953	2.560738	1.842951	4.415794
79.61114	22.36364	9.391561	253.2078	262.5993	525.[illegible]87	4.054970	4.049417	22.33301	2.021936	3.334744	3.072885	2.211542	5.298953
79.61114	26.09091	14.91345	402.0846	416.9980	833.9960	4.730798	4.724320	26.05518	2.358925	3.890534	3.585033	2.580132	6.182112
79.61114	29.81818	22.26148	600.1962	622.4577	1244.915	5.406626	5.399223	29.77735	2.695915	4.446325	4.097180	2.948722	7.065271

Calculate Torospherical Shape Dimensions to Match a Given Set of Input Dimensions.

C.G. radius x (ft)	surface area Head As (sq ft)	surface area Buoy Ab (sq ft)	operating depth d assign (ft)	working pressure p (psi)	material allowable stress Sa (ksi)	knuckle stress multipl'r m table	thick shell t (inches)	Buoy pressure vessel weight Wb (pounds)	Buoy thin shell weight Wt 1/8"plate (pounds)	Total water displaced Dg (cu ft)	Net buoyancy (pounds)	Efficiency E (%)
CASE ONE: CROWN HEIGHT RATIO = 1:1 = SPHERICAL SHAPE (continued)												
.6366198	6.283185	12.56637	2000	892	24	1.33	.2904900	148.9365	64.08849	269.3392102	120.4027	44.70
1.273240	25.13274	50.26548	2000	892	24	1.33	.5809799	1191.492	256.3540	2154.713681	963.2217	44.70
1.909859	56.54867	113.0973	2000	892	24	1.33	.8714699	4021.285	576.7964	7272.158675	3250.873	44.70
2.546479	100.5310	201.0619	2000	892	24	1.33	1.161960	9531.936	1025.416	17237.70945	7705.773	44.70
3.183099	157.0796	314.1593	2000	892	24	1.33	1.452450	18617.06	1602.212	33667.40127	15050.34	44.70
3.819719	226.1947	452.3893	2000	892	24	1.33	1.742940	32170.28	2307.186	58177.26940	26006.99	44.70
4.456338	307.8761	615.7522	2000	892	24	1.33	2.033430	51085.22	3140.336	92383.34909	41298.13	44.70
5.092958	402.1239	804.2477	2000	892	24	1.33	2.323920	76255.49	4101.663	137901.6756	61646.19	44.70
CASE TWO: CROWN HEIGHT RATIO 1:1.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5 (continued)												
.6041694	5.386662	10.77332	2000	892	24	1.33	.2998005	131.7778	54.94395	211.5872[illegible]5	79.80940	37.72
1.208339	21.54665	43.09329	2000	892	24	1.33	.5996011	1054.222	219.7758	1692.697660	638.4752	37.72
2.416678	86.18659	172.3732	2000	892	24	1.33	1.199202	8433.779	879.1032	13541.58128	5107.802	37.72
3.020847	134.6665	269.3331	2000	892	24	1.33	1.499003	16472.23	1373.599	26448.40094	9976.176	37.72
3.625017	193.9198	387.8397	2000	892	24	1.33	1.798803	28464.01	1977.982	45702.83683	17238.83	37.72
4.229186	263.9464	527.8929	2000	892	24	1.33	2.098604	45199.79	2692.254	72574.41218	27374.63	37.72
4.833355	344.7464	689.4927	2000	892	24	1.33	2.398404	67470.24	3516.413	108332.6503	40862.42	37.72
CASE THREE: CROWN HEIGHT RATIO 1:1.4, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5 (continued)												
.5899476	4.939847	9.879694	2000	892	24	1.33	.3282159	132.3011	50.38644	182.9682902	50.66724	27.69
1.179895	19.75939	39.51878	2000	892	24	1.33	.6564318	1058.408	201.5458	1463.746321	405.3379	27.69
1.769843	44.45862	88.91725	2000	892	24	1.33	.9846478	3572.128	453.4780	4940.143834	1368.015	27.69
2.359790	79.03755	158.0751	2000	892	24	1.33	1.312864	8467.267	806.1830	11709.97057	3242.703	27.69
2.949738	123.4962	246.9923	2000	892	24	1.33	1.641080	16537.63	1259.661	22871.03627	6333.405	27.69
3.539685	177.8345	355.6690	2000	892	24	1.33	1.969296	28577.03	1813.912	39521.15068	10944.12	27.69
4.129633	242.0525	484.1050	2000	892	24	1.33	2.297511	45379.26	2468.936	62758.12353	17378.86	27.69
4.719581	316.1502	632.3004	2000	892	24	1.33	2.625727	67738.14	3224.732	93679.76456	25941.63	27.69
CASE FOUR: CROWN HEIGHT RATIO 1:1.6, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5 (continued)												
.5846063	4.712978	9.425955	2000	892	24	1.33	.3812681	146.6277	48.07237	169.0429432	22.41526	13.26
1.169213	18.85191	37.70382	2000	892	24	1.33	.7625361	1173.021	192.2895	1352.343546	179.3221	13.26
1.753819	42.41680	84.83360	2000	892	24	1.33	1.143804	3958.947	432.6514	4564.159467	605.2120	13.26
2.338425	75.40764	150.8153	2000	892	24	1.33	1.525072	9384.172	769.1580	10818.74837	1434.577	13.26
2.923031	117.8244	235.6489	2000	892	24	1.33	1.906340	18328.46	1201.809	21130.36790	2801.908	13.26
3.507638	169.6672	339.3344	2000	892	24	1.33	2.287608	31671.58	1730.605	36513.27574	4841.696	13.26
4.092244	230.9359	461.8718	2000	892	24	1.33	2.668876	50293.30	2355.546	57981.72952	7688.434	13.26
4.676850	301.6306	603.2611	2000	892	24	1.33	3.050145	75073.37	3076.632	86549.98693	11476.61	13.26
CASE FIVE: CROWN HEIGHT RATIO 1:1.8, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5 (continued)												
.5831524	4.597851	9.195703	2000	892	24	1.33	.4749280	178.1857	46.89808	162.3300693	**-15.8556**	**-9.77**
1.166305	18.39141	36.78281	2000	892	24	1.33	.9498560	1425.486	187.5923	1298.640554	**-126.845**	**-9.77**
1.749457	41.38066	82.76132	2000	892	24	1.33	1.424784	4811.014	422.0827	4382.911870	**-428.102**	**-9.77**
2.332610	73.56562	147.1312	2000	892	24	1.33	1.899712	11403.89	750.3693	10389.12443	**-1014.76**	**-9.77**
2.915762	114.9463	229.3926	2000	892	24	1.33	2.374640	22273.21	1172.452	20291.25866	**-1981.96**	**-9.77**
3.498915	165.5226	331.0453	2000	892	24	1.33	2.849568	38488.11	1688.331	35063.29496	**-3424.82**	**-9.77**
4.082067	225.2947	450.5894	2000	892	24	1.33	3.324496	61117.70	2298.006	55679.21375	**-5438.48**	**-9.77**
4.665220	294.2625	588.5250	2000	892	24	1.33	3.799424	91231.08	3001.477	83112.99546	**-8118.09**	**-9.77**
CASE SIX: CROWN HEIGHT RATIO 1:2.0, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5 (continued)												
.5831354	4.540982	9.081964	2000	892	24	1.33	.6536024	242.1885	46.31802	158.7765957	**-83.4119**	**-52.53**
1.166271	18.16393	36.32786	2000	892	24	1.33	1.307205	1937.508	185.2721	1270.212765	**-667.296**	**-52.53**
1.749406	40.86884	81.73768	2000	892	24	1.33	1.960807	6539.091	416.8622	4286.968083	**-2252.12**	**-52.53**
2.332542	72.65571	145.3114	2000	892	24	1.33	2.614410	15500.07	741.0863	10161.70212	**-5338.36**	**-52.53**
2.915677	113.5246	227.0491	2000	892	24	1.33	3.268012	30273.57	1157.950	19847.07446	**-10426.5**	**-52.53**
3.498813	163.4751	326.9507	2000	892	24	1.33	3.921614	52312.72	1667.449	34295.74466	**-18017.0**	**-52.53**
4.081948	222.5081	445.0162	2000	892	24	1.33	4.575217	83070.67	2269.5[illegible]	5[illegible]460.37231	**-28610.3**	**-52.53**
4.665083	290.6229	581.2457	2000	892	24	1.33	5.228819	124000.5	2964.353	81293.61698	**-42706.9**	**-52.53**
CASE SEVEN: CROWN HEIGHT RATIO 1:2.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 2.5 (continued)												
.5834584	4.515087	9.030173	2000	892	24	1.33	1.082735	398.9133	46.05388	156.3438574	**-242.569**	**-155.15**
1.166917	18.06035	36.12069	2000	892	24	1.33	2.165471	3191.306	184.2155	1250.750859	**-1940.56**	**-155.15**
1.750375	40.63578	81.27156	2000	892	24	1.33	3.248206	10770.66	414.4849	4221.284151	**-6549.38**	**-155.15**
2.333833	72.24138	144.4828	2000	892	24	1.33	4.330941	25530.45	736.8621	10006.00688	**-15524.4**	**-155.15**
2.917292	112.8772	225.7543	2000	892	24	1.33	5.413676	49864.16	1151.347	19542.98218	**-30321.2**	**-155.15**
3.500750	162.5431	325.0862	2000	892	24	1.33	6.496412	86165.27	1657.940	33770.27320	**-52395.0**	**-155.15**
4.084209	221.2392	442.4785	2000	892	24	1.33	7.579147	136827.3	2256.640	53625.94310	**-83201.3**	**-155.15**
4.667667	288.9655	577.9311	2000	892	24	1.33	8.661882	204243.6	2947.448	80048.05500	**-124196.**	**-155.15**

Part 2

July 17, 1990

Calculate Torospherical Shape Dimensions to Match a Given Set of Input Dimensions.

57.29578

Buoy Radius W Major 1/2 axis ft	height ratio a input -	flange ratio f input -	crown height H Minor 1/2 axis ft	inverse 1/f calc -	flange radius r calc ft	j calc ft	w calc ft	psi calc radians	psi degrees	crown 1/2 angle phi calc radians	phi degrees	Crown height c calc ft	flange arc theta calc radians
CASE EIGHT: CROWN HEIGHT RATIO 1:1, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0													
1	1	3	1	.3333333	.3333333	.6666667	.6666667	.7853982	45	1.570796	90	1	6.66e-16
2	1	3	2	.3333333	.6666667	1.333333	1.333333	.7853982	45	1.570796	90	2	6.66e-16
3	1	3	3	.3333333	1	2	2	.7853982	45	1.570796	90	3	6.66e-16
4	1	3	4	.3333333	1.333333	2.666667	2.666667	.7853982	45	1.570796	90	4	6.66e-16
5	1	3	5	.3333333	1.666667	3.333333	3.333333	.7853982	45	1.570796	90	5	6.66e-16
6	1	3	6	.3333333	2	4	4	.7853982	45	1.570796	90	6	6.66e-16
7	1	3	7	.3333333	2.333333	4.666667	4.666667	.7853982	45	1.570796	90	7	6.66e-16
8	1	3	8	.3333333	2.666667	5.333333	5.333333	.7853982	45	1.570796	90	8	6.66e-16
CASE NINE: CROWN HEIGHT RATIO 1:1.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0													
1	1.2	3	.8333333	.3333333	.3333333	.5	.6666667	.6435011	36.86990	1.287002	73.73980	.74	.2837941
2	1.2	3	1.666667	.3333333	.6666667	1	1.333333	.6435011	36.86990	1.287002	73.73980	1.48	.2837941
4	1.2	3	3.333333	.3333333	1.333333	2	2.666667	.6435011	36.86990	1.287002	73.73980	2.96	.2837941
5	1.2	3	4.166667	.3333333	1.666667	2.5	3.333333	.6435011	36.86990	1.287002	73.73980	3.7	.2837941
6	1.2	3	5	.3333333	2	3	4	.6435011	36.86990	1.287002	73.73980	4.44	.2837941
7	1.2	3	5.833333	.3333333	2.333333	3.5	4.666667	.6435011	36.86990	1.287002	73.73980	5.18	.2837941
8	1.2	3	6.666667	.3333333	2.666667	4	5.333333	.6435011	36.86990	1.287002	73.73980	5.92	.2837941
CASE TEN: CROWN HEIGHT RATIO 1:1.4, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0													
1	1.4	3	.7142857	.3333333	.3333333	.3809524	.6666667	.5191461	29.74488	1.038292	59.48976	.5450549	.5325041
2	1.4	3	1.428571	.3333333	.6666667	.7619048	1.333333	.5191461	29.74488	1.038292	59.48976	1.090110	.5325041
3	1.4	3	2.142857	.3333333	1	1.142857	2	.5191461	29.74488	1.038292	59.48976	1.635165	.5325041
4	1.4	3	2.857143	.3333333	1.333333	1.523810	2.666667	.5191461	29.74488	1.038292	59.48976	2.180220	.5325041
5	1.4	3	3.571429	.3333333	1.666667	1.904762	3.333333	.5191461	29.74488	1.038292	59.48976	2.725275	.5325041
6	1.4	3	4.285714	.3333333	2	2.285714	4	.5191461	29.74488	1.038292	59.48976	3.270330	.5325041
7	1.4	3	5	.3333333	2.333333	2.666667	4.666667	.5191461	29.74488	1.038292	59.48976	3.815385	.5325041
8	1.4	3	5.714286	.3333333	2.666667	3.047619	5.333333	.5191461	29.74488	1.038292	59.48976	4.360440	.5325041
CASE ELEVEN: CROWN HEIGHT RATIO 1:1.6, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0													
1	1.6	3	.625	.3333333	.3333333	.2916667	.6666667	.4124104	23.62938	.8248209	47.25876	.3987705	.7459754
2	1.6	3	1.25	.3333333	.6666667	.5833333	1.333333	.4124104	23.62938	.8248209	47.25876	.7975410	.7459754
3	1.6	3	1.875	.3333333	1	.875	2	.4124104	23.62938	.8248209	47.25876	1.196311	.7459754
4	1.6	3	2.5	.3333333	1.333333	1.166667	2.666667	.4124104	23.62938	.8248209	47.25876	1.595082	.7459754
5	1.6	3	3.125	.3333333	1.666667	1.458333	3.333333	.4124104	23.62938	.8248209	47.25876	1.993852	.7459754
6	1.6	3	3.75	.3333333	2	1.75	4	.4124104	23.62938	.8248209	47.25876	2.392623	.7459754
7	1.6	3	4.375	.3333333	2.333333	2.041667	4.666667	.4124104	23.62938	.8248209	47.25876	2.791393	.7459754
8	1.6	3	5	.3333333	2.666667	2.333333	5.333333	.4124104	23.62938	.8248209	47.25876	3.190164	.7459754
CASE TWELVE: CROWN HEIGHT RATIO 1:1.8, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0													
1	1.8	3	.5555556	.3333333	.3333333	.2222222	.6666667	.3217506	18.43495	.6435011	36.86990	.2888889	.9272952
2	1.8	3	1.111111	.3333333	.6666667	.4444444	1.333333	.3217506	18.43495	.6435011	36.86990	.5777778	.9272952
3	1.8	3	1.666667	.3333333	1	.6666667	2	.3217506	18.43495	.6435011	36.86990	.8666667	.9272952
4	1.8	3	2.222222	.3333333	1.333333	.8888889	2.666667	.3217506	18.43495	.6435011	36.86990	1.155556	.9272952
5	1.8	3	2.777778	.3333333	1.666667	1.111111	3.333333	.3217506	18.43495	.6435011	36.86990	1.444444	.9272952
6	1.8	3	3.333333	.3333333	2	1.333333	4	.3217506	18.43495	.6435011	36.86990	1.733333	.9272952
7	1.8	3	3.888889	.3333333	2.333333	1.555556	4.666667	.3217506	18.43495	.6435011	36.86990	2.022222	.9272952
8	1.8	3	4.444444	.3333333	2.666667	1.777778	5.333333	.3217506	18.43495	.6435011	36.86990	2.311111	.9272952
CASE THIRTEEN: CROWN HEIGHT RATIO 1:2.0, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0													
1	2	3	.5	.3333333	.3333333	.1666667	.6666667	.2449787	14.03624	.4899573	28.07249	.2058824	1.080839
2	2	3	1	.3333333	.6666667	.3333333	1.333333	.2449787	14.03624	.4899573	28.07249	.4117647	1.080839
3	2	3	1.5	.3333333	1	.5	2	.2449787	14.03624	.4899573	28.07249	.6176471	1.080839
4	2	3	2	.3333333	1.333333	.6666667	2.666667	.2449787	14.03624	.4899573	28.07249	.8235294	1.080839
5	2	3	2.5	.3333333	1.666667	.8333333	3.333333	.2449787	14.03624	.4899573	28.07249	1.029412	1.080839
6	2	3	3	.3333333	2	1	4	.2449787	14.03624	.4899573	28.07249	1.235294	1.080839
7	2	3	3.5	.3333333	2.333333	1.166667	4.666667	.2449787	14.03624	.4899573	28.07249	1.441176	1.080839
8	2	3	4	.3333333	2.666667	1.333333	5.333333	.2449787	14.03624	.4899573	28.07249	1.647059	1.080839
CASE FOURTEEN: CROWN HEIGHT RATIO 1:2.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0													
1	2.2	3	.4545455	.3333333	.3333333	.1212121	.6666667	.1798535	10.30485	.3597070	20.60969	.1425455	1.211089
2	2.2	3	.9090909	.3333333	.6666667	.2424242	1.333333	.1798535	10.30485	.3597070	20.60969	.2850909	1.211089
3	2.2	3	1.363636	.3333333	1	.3636364	2	.1798535	10.30485	.3597070	20.60969	.4276364	1.211089
4	2.2	3	1.818182	.3333333	1.333333	.4848485	2.666667	.1798535	10.30485	.3597070	20.60969	.5701818	1.211089
5	2.2	3	2.272727	.3333333	1.666667	.6060606	3.333333	.1798535	10.30485	.3597070	20.60969	.7127273	1.211089
6	2.2	3	2.727273	.3333333	2	.7272727	4	.1798535	10.30485	.3597070	20.60969	.8552727	1.211089
7	2.2	3	3.181818	.3333333	2.333333	.8484848	4.666667	.1798535	10.30485	.3597070	20.60969	.9978182	1.211089
8	2.2	3	3.636364	.3333333	2.666667	.9696970	5.333333	.1798535	10.30485	.3597070	20.60969	1.140364	1.211089

Part 2 (continued)

July 17, 1990

Calculate Torospherical Shape Dimensions to Match a Given Set of Input Dimensions.

	crown radius	crown volume	flange volume	volume end bell	volume buoy	---------parameters to derive C.G. of section---------							
theta	R	Vc	Vf	Ve	Vb	l1	c1	d1	s1	l2	c2	d2	s2
degrees	calc ft	calc cu ft	calc cu ft	calc cu ft	calc cu ft	ft	ft	ft	ft	ft	ft	ft	ft
CASE EIGHT: CROWN HEIGHT RATIO 1:1, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)													
3.82e-14	1	2.094395	0	2.094395	4.188790	1.570796	1.414214	.9003163	.6366198	2.22e-16	0	0	.6666667
3.82e-14	2	16.75516	0	16.75516	33.51032	3.141593	2.828427	1.800633	1.273240	4.44e-16	0	0	1.333333
3.82e-14	3	56.54867	0	56.54867	113.0973	4.712389	4.242641	2.700949	1.909859	6.66e-16	0	0	2
3.82e-14	4	134.0413	0	134.0413	268.0826	6.283185	5.656854	3.601265	2.546479	8.88e-16	0	0	2.666667
3.82e-14	5	261.7994	0	261.7994	523.5988	7.853982	7.071068	4.501582	3.183099	1.11e-15	0	0	3.333333
3.82e-14	6	452.3893	0	452.3893	904.7787	9.424778	8.485281	5.401898	3.819719	1.33e-15	0	0	4
3.82e-14	7	718.3775	0	718.3775	1436.755	10.99557	9.899495	6.302214	4.456338	1.55e-15	0	0	4.666667
3.82e-14	8	1072.330	0	1072.330	2144.661	12.56637	11.31371	7.202531	5.092958	1.78e-15	0	0	5.333333
CASE NINE: CROWN HEIGHT RATIO 1:1.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)													
16.26020	1.027778	1.343774	.2923639	1.636138	3.272275	1.322752	1.233333	.9582993	.5749796	.0945980	.0942809	.3322159	.9955436
16.26020	2.055556	10.75019	2.338911	13.08910	26.17820	2.645505	2.466667	1.916599	1.149959	.1891961	.1885618	.6644317	1.991087
16.26020	4.111111	86.00151	18.71129	104.7128	209.4256	5.291009	4.933333	3.833197	2.299918	.3783921	.3771236	1.328863	3.982174
16.26020	5.138889	167.9717	36.54549	204.5172	409.0344	6.613761	6.166667	4.791497	2.874898	.4729902	.4714045	1.661079	4.977718
16.26020	6.166667	290.2551	63.15060	353.4057	706.8114	7.936514	7.4	5.749796	3.449878	.5675882	.5656854	1.993295	5.973262
16.26020	7.194444	460.9144	100.2808	561.1952	1122.390	9.259266	8.633333	6.708095	4.024857	.6621863	.6599663	2.325511	6.968805
16.26020	8.222222	688.0121	149.6903	837.7024	1675.405	10.58202	9.866667	7.666394	4.599837	.7567843	.7542472	2.657727	7.964349
CASE TEN: CROWN HEIGHT RATIO 1:1.4, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)													
30.51024	1.107143	.8637481	.5265788	1.390327	2.780654	1.149538	1.098593	1.058077	.5249533	.1775014	.1754116	.3294089	.9844685
30.51024	2.214286	6.909985	4.212630	11.12261	22.24523	2.299076	2.197187	2.116154	1.049907	.3550027	.3508232	.6588179	1.968937
30.51024	3.321429	23.32120	14.21763	37.53883	75.07765	3.448613	3.295780	3.174232	1.574860	.5325041	.5262348	.9882268	2.953405
30.51024	4.428571	55.27988	33.70104	88.98092	177.9618	4.598151	4.394373	4.232309	2.099813	.7100055	.7016464	1.317636	3.937874
30.51024	5.535714	107.9685	65.82235	173.7909	347.5817	5.747689	5.492967	5.290386	2.624767	.8875068	.8770580	1.647045	4.922342
30.51024	6.642857	186.5696	113.7410	300.3106	600.6212	6.897227	6.591560	6.348463	3.149720	1.065008	1.052470	1.976454	5.906811
30.51024	7.75	296.2656	180.6165	476.8821	953.7642	8.046765	7.690154	7.406541	3.674673	1.242510	1.227881	2.305862	6.891279
30.51024	8.857143	442.2390	269.6083	711.8474	1423.695	9.196303	8.788747	8.464618	4.199627	1.420011	1.403293	2.635271	7.875748
CASE ELEVEN: CROWN HEIGHT RATIO 1:1.6, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)													
42.74124	1.241071	.5535969	.6985961	1.252193	2.504386	1.023662	.9948896	1.206189	.4834631	.2486585	.2429329	.3256580	.9699334
42.74124	2.482143	4.428775	5.588769	10.01754	20.03509	2.047323	1.989779	2.412377	.9669263	.4973170	.4858658	.6513161	1.939867
42.74124	3.723214	14.94712	18.86209	33.80921	67.61842	3.070985	2.984669	3.618566	1.450389	.7459754	.7287987	.9769741	2.909800
42.74124	4.964286	35.43020	44.71015	80.14035	160.2807	4.094647	3.979558	4.824755	1.933853	.9946339	.9717316	1.302632	3.879733
42.74124	6.205357	69.19961	87.32451	156.5241	313.0482	5.118308	4.974448	6.030943	2.417316	1.243292	1.214664	1.628290	4.849667
42.74124	7.446429	119.5769	150.8968	270.4737	540.9474	6.141970	5.969338	7.237132	2.900779	1.491951	1.457597	1.953948	5.819600
42.74124	8.6875	189.8837	239.6185	429.5022	859.0044	7.165631	6.964227	8.443321	3.384242	1.740609	1.700530	2.279606	6.789534
42.74124	9.928571	283.4416	357.6812	641.1228	1282.246	8.189293	7.959117	9.649509	3.867705	1.989268	1.943463	2.605264	7.759467
CASE TWELVE: CROWN HEIGHT RATIO 1:1.8, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)													
53.13010	1.444444	.3534672	.8179001	1.171367	2.342735	.9295016	.9135469	1.419651	.4489330	.3090984	.2981424	.3215183	.9542414
53.13010	2.888889	2.827738	6.543201	9.370939	18.74188	1.859003	1.827094	2.839302	.8978660	.6181968	.5962848	.6430366	1.908483
53.13010	4.333333	9.543615	22.08330	31.62692	63.25383	2.788505	2.740641	4.258952	1.346799	.9272952	.8944272	.9645549	2.862724
53.13010	5.777778	22.62190	52.34560	74.96751	149.9350	3.718006	3.654188	5.678603	1.795732	1.236394	1.192570	1.286073	3.816966
53.13010	7.222222	44.18341	102.2375	146.4209	292.8418	4.647508	4.567734	7.098254	2.244665	1.545492	1.490712	1.607592	4.771207
53.13010	8.666667	76.34892	176.6664	253.0153	506.0307	5.577010	5.481281	8.517905	2.693598	1.854590	1.788854	1.929110	5.725448
53.13010	10.11111	121.2393	280.5397	401.7790	803.5580	6.506511	6.394828	9.937556	3.142531	2.163689	2.086997	2.250628	6.679690
53.13010	11.55556	180.9752	418.7648	599.7401	1199.480	7.436013	7.308375	11.35721	3.591464	2.472787	2.385139	2.572147	7.633931
CASE THIRTEEN: CROWN HEIGHT RATIO 1:2.0, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)													
61.92751	1.75	.2238990	.8973543	1.121253	2.242507	.8574253	.8488747	1.732548	.4202047	.3602797	.3429972	.3173434	.9387864
61.92751	3.5	1.791192	7.178834	8.970026	17.94005	1.714851	1.697749	3.465096	.8404093	.7205593	.6859943	.6346869	1.877573
61.92751	5.25	6.045272	24.22857	30.27384	60.54768	2.572276	2.546624	5.197645	1.260614	1.080839	1.028992	.9520303	2.816359
61.92751	7	14.32953	57.43068	71.76021	143.5204	3.429701	3.395499	6.930193	1.680819	1.441119	1.371989	1.269374	3.755146
61.92751	8.75	27.98737	112.1693	140.1567	280.3133	4.287127	4.244373	8.662741	2.101023	1.801398	1.714986	1.586717	4.693932
61.92751	10.5	48.36217	193.8285	242.1907	484.3814	5.144552	5.093248	10.39529	2.521228	2.161678	2.057983	1.904061	5.632719
61.92751	12.25	76.79734	307.7925	384.5899	769.1797	6.001977	5.942123	12.12784	2.941433	2.521958	2.400980	2.221404	6.571505
61.92751	14	114.6363	459.4454	574.0817	1148.163	6.859403	6.790998	13.86039	3.361637	2.882237	2.743977	2.538748	7.510291
CASE FOURTEEN: CROWN HEIGHT RATIO 1:2.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)													
69.39031	2.227273	.1391441	.9483721	1.087516	2.175032	.8011656	.7968533	2.215284	.3962821	.4036964	.3794733	.3133322	.9242860
69.39031	4.454545	1.113153	7.586977	8.700130	17.40026	1.602331	1.593707	4.430569	.7925643	.8073929	.7589466	.6266645	1.848572
69.39031	6.681818	3.756891	25.60605	29.36294	58.72588	2.403497	2.390560	6.645853	1.188846	1.211089	1.138420	.9399967	2.772858
69.39031	8.909091	8.905223	60.69582	69.60104	139.2021	3.204662	3.187413	8.861138	1.585129	1.614786	1.517893	1.253329	3.697144
69.39031	11.13636	17.39301	118.5465	135.9395	271.8791	4.005828	3.984267	11.07642	1.981411	2.018482	1.897367	1.566661	4.621430
69.39031	13.36364	30.05513	204.8484	234.9035	469.8070	4.806994	4.781120	13.29171	2.377693	2.422179	2.276840	1.879993	5.545716
69.39031	15.59091	47.72643	325.2916	373.0181	746.0361	5.608159	5.577973	15.50699	2.773975	2.825875	2.656313	2.193326	6.470002
69.39031	17.81818	71.24178	485.5665	556.8083	1113.617	6.409325	6.374827	17.72228	3.170257	3.229572	3.035787	2.506658	7.394288

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Calculate Torospherical Shape Dimensions to Match a Given Set of Input Dimensions.

APPENDIX 5 Part 2 (continued)

C.G. radius x ft	surface area Head As sq ft	surface area Buoy Ab sq ft	operating depth d assign ft	working pressure p psi	material allowable stress Sa assign ksi	knuckle stress multipl'r m lookup	thick shell t inches	Buoy pressure vessel weight Wb pounds	Buoy thin shell weight Wt pounds	Total water displaced Dg cu ft	Net buoyancy pounds	Efficiency E %
CASE EIGHT: CROWN HEIGHT RATIO 1:1, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)												
.6366198	6.283185	12.56637	2000	892	24	1.37	.2990088	153.3042	64.08849	269.3392102	116.0350	43.08
1.273240	25.13274	50.26548	2000	892	24	1.37	.5980176	1226.433	256.3540	2154.713681	928.2802	43.08
1.909859	56.54867	113.0973	2000	892	24	1.37	.8970264	4139.213	576.7964	7272.158675	3132.946	43.08
2.546479	100.5310	201.0619	2000	892	24	1.37	1.196035	9811.468	1025.416	17237.70945	7426.242	43.08
3.183099	157.0796	314.1593	2000	892	24	1.37	1.495044	19163.02	1602.212	33667.40127	14504.38	43.08
3.819719	226.1947	452.3893	2000	892	24	1.37	1.794053	33113.70	2307.186	58177.26940	25063.57	43.08
4.456338	307.8761	615.7522	2000	892	24	1.37	2.093062	52583.33	3140.336	92383.34909	39800.02	43.08
5.092958	402.1239	804.2477	2000	892	24	1.37	2.392070	78491.74	4101.663	137901.6756	59409.94	43.08
CASE NINE: CROWN HEIGHT RATIO 1:1.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)												
.6030492	5.370440	10.74088	2000	892	24	1.37	.3073146	134.6738	54.77848	210.4072922	75.73347	35.99
1.206098	21.48176	42.96352	2000	892	24	1.37	.6146292	1077.391	219.1139	1683.258338	605.8677	35.99
2.412197	85.92704	171.8541	2000	892	24	1.37	1.229258	8619.125	876.4558	13466.06670	4846.942	35.99
3.015246	134.2610	268.5220	2000	892	24	1.37	1.536573	16834.23	1369.462	26300.91153	9466.683	35.99
3.618295	193.3358	386.6717	2000	892	24	1.37	1.843888	29089.55	1972.025	45447.97512	16358.43	35.99
4.221345	263.1515	526.3031	2000	892	24	1.37	2.151202	46193.12	2684.146	72169.70123	25976.58	35.99
4.824394	343.7081	687.4163	2000	892	24	1.37	2.458517	68953.00	3505.823	107728.5336	38775.53	35.99
CASE TEN: CROWN HEIGHT RATIO 1:1.4, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)												
.5864169	4.889563	9.779127	2000	892	24	1.37	.3310455	132.0833	49.87355	178.7960351	46.71275	26.13
1.172834	19.55825	39.11651	2000	892	24	1.37	.6620909	1056.666	199.4942	1430.368281	373.7020	26.13
1.759251	44.00607	88.01214	2000	892	24	1.37	.9931364	3566.249	448.8619	4827.492949	1261.244	26.13
2.345668	78.23301	156.4660	2000	892	24	1.37	1.324182	8453.331	797.9768	11442.94625	2989.616	26.13
2.932084	122.2391	244.4782	2000	892	24	1.37	1.655227	16510.41	1246.839	22349.50439	5839.093	26.13
3.518501	176.0243	352.0486	2000	892	24	1.37	1.986273	28529.99	1795.448	38619.94359	10089.95	26.13
4.104918	239.5886	479.1772	2000	892	24	1.37	2.317318	45304.57	2443.804	61327.04006	16022.47	26.13
4.691335	312.9321	625.8641	2000	892	24	1.37	2.648364	67626.64	3191.907	91543.57000	23916.93	26.13
CASE ELEVEN: CROWN HEIGHT RATIO 1:1.6, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)												
.5785374	4.624957	9.249915	2000	892	24	1.37	.3710913	140.0486	47.17456	161.0320198	20.98346	13.03
1.157075	18.49983	36.99966	2000	892	24	1.37	.7421826	1120.388	188.6983	1288.256158	167.8677	13.03
1.735612	41.62462	83.24923	2000	892	24	1.37	1.113274	3781.311	424.5711	4347.864533	566.5535	13.03
2.314150	73.99932	147.9986	2000	892	24	1.37	1.484365	8963.108	754.7930	10306.04926	1342.942	13.03
2.892687	115.6239	231.2479	2000	892	24	1.37	1.855456	17506.07	1179.364	20129.00247	2622.933	13.03
3.471225	166.4985	332.9969	2000	892	24	1.37	2.226548	30250.49	1698.284	34782.91627	4532.428	13.03
4.049762	226.6229	453.2458	2000	892	24	1.37	2.597639	48036.66	2311.554	55233.98278	7197.328	13.03
4.628300	295.9973	591.9945	2000	892	24	1.37	2.968730	71704.86	3019.172	82448.39412	10743.53	13.03
CASE TWELVE: CROWN HEIGHT RATIO 1:1.8, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)												
.5750351	4.475126	8.950252	2000	892	24	1.37	.4319016	157.7176	45.64629	150.6378364	**-7.07980**	**-4.70**
1.150070	17.90050	35.80101	2000	892	24	1.37	.8638032	1261.741	182.5851	1205.102692	**-56.6384**	**-4.70**
1.725105	40.27614	80.55227	2000	892	24	1.37	1.295705	4258.376	410.8166	4067.221584	**-191.155**	**-4.70**
2.300140	71.60202	143.2040	2000	892	24	1.37	1.727606	10093.93	730.3406	9640.821533	**-453.107**	**-4.70**
2.875175	111.8782	223.7563	2000	892	24	1.37	2.159508	19714.70	1141.157	18829.72956	**-884.975**	**-4.70**
3.450210	161.1045	322.2091	2000	892	24	1.37	2.591410	34067.01	1643.266	32537.77267	**-1529.24**	**-4.70**
4.025245	219.2812	438.5624	2000	892	24	1.37	3.023311	54097.15	2236.668	51668.77790	**-2428.37**	**-4.70**
4.600281	286.4081	572.8161	2000	892	24	1.37	3.455213	80751.43	2921.362	77126.57226	**-3624.86**	**-4.70**
CASE THIRTEEN: CROWN HEIGHT RATIO 1:2.0, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)												
.5736363	4.388929	8.777858	2000	892	24	1.37	.5232654	187.4005	44.76708	144.1931693	**-43.2073**	**-29.96**
1.147273	17.55572	35.11143	2000	892	24	1.37	1.046531	1499.204	179.0683	1153.545354	**-345.659**	**-29.96**
1.720909	39.50036	79.00073	2000	892	24	1.37	1.569796	5059.814	402.9037	3893.215571	**-1166.60**	**-29.96**
2.294545	70.22287	140.4457	2000	892	24	1.37	2.093062	11993.63	716.2732	9228.362834	**-2765.27**	**-29.96**
2.868181	109.7232	219.4465	2000	892	24	1.37	2.616327	23425.06	1119.177	18024.14616	**-5400.92**	**-29.96**
3.441818	158.0015	316.0029	2000	892	24	1.37	3.139592	40478.51	1611.615	31145.72457	**-9332.78**	**-29.96**
4.015454	215.0575	430.1151	2000	892	24	1.37	3.662858	64278.37	2193.587	49458.25706	**-14820.1**	**-29.96**
4.589090	280.8915	561.7829	2000	892	24	1.37	4.186123	95949.06	2865.093	73826.90267	**-22122.2**	**-29.96**
CASE FOURTEEN: CROWN HEIGHT RATIO 1:2.2, FLANGE TO MAJOR AXIS RATIO (W/r) = 3.0 (continued)												
.5731931	4.339284	8.678569	2000	892	24	1.37	.6659741	235.8119	44.26070	139.8545876	**-95.9573**	**-68.61**
1.146386	17.35714	34.71428	2000	892	24	1.37	1.331948	1886.495	177.0428	1118.836701	**-767.658**	**-68.61**
1.719579	39.05356	78.10712	2000	892	24	1.37	1.997922	6366.920	398.3463	3776.073866	**-2590.85**	**-68.61**
2.292772	69.42855	138.8571	2000	892	24	1.37	2.663897	15091.96	708.1712	8950.693609	**-6141.27**	**-68.61**
2.865965	108.4821	216.9642	2000	892	24	1.37	3.329871	29476.48	1106.518	17481.82346	**-11994.7**	**-68.61**
3.439158	156.2142	312.4285	2000	892	24	1.37	3.995845	50935.36	1593.385	30208.59093	**-20726.8**	**-68.61**
4.012351	212.6249	425.2499	2000	892	24	1.37	4.661819	80883.47	2168.774	47970.12356	**-32913.3**	**-68.61**
4.585545	277.7142	555.4284	2000	892	24	1.37	5.327793	120735.7	2832.685	71605.54887	**-49130.1**	**-68.61**

Part 3

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Calculate Torospherical Shape Dimensions to Match a Given Set of Input Dimensions.

57.29578 W Major 1/2 axis ft	height ratio a input -	flange ratio f input -	crown height H Minor 1/2 axis ft	inverse 1/f calc -	flange radius r calc ft	j calc ft	w calc ft	psi calc radians	psi degrees	crown 1/2 angle phi calc radians	phi degrees	Crown height c calc ft	flange arc theta calc radians
CASE FIFTEEN: CROWN HEIGHT RATIO 1:1.0, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5													
1	1	3.5	1	.2857143	.2857143	.7142857	.7142857	.7853982	45	1.570796	90	1	6.66e-16
2	1	3.5	2	.2857143	.5714286	1.428571	1.428571	.7853982	45	1.570796	90	2	6.66e-16
3	1	3.5	3	.2857143	.8571429	2.142857	2.142857	.7853982	45	1.570796	90	3	6.66e-16
4	1	3.5	4	.2857143	1.142857	2.857143	2.857143	.7853982	45	1.570796	90	4	6.66e-16
5	1	3.5	5	.2857143	1.428571	3.571429	3.571429	.7853982	45	1.570796	90	5	6.66e-16
6	1	3.5	6	.2857143	1.714286	4.285714	4.285714	.7853982	45	1.570796	90	6	6.66e-16
7	1	3.5	7	.2857143	2	5	5	.7853982	45	1.570796	90	7	6.66e-16
8	1	3.5	8	.2857143	2.285714	5.714286	5.714286	.7853982	45	1.570796	90	8	6.66e-16
CASE SIXTEEN: CROWN HEIGHT RATIO 1:1.2, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5													
1	1.2	3.5	.8333333	.2857143	.2857143	.5476190	.7142857	.6540827	37.47618	1.308165	74.95236	.7591556	.2626309
2	1.2	3.5	1.666667	.2857143	.5714286	1.095238	1.428571	.6540827	37.47618	1.308165	74.95236	1.518311	.2626309
4	1.2	3.5	3.333333	.2857143	1.142857	2.190476	2.857143	.6540827	37.47618	1.308165	74.95236	3.036622	.2626309
5	1.2	3.5	4.166667	.2857143	1.428571	2.738095	3.571429	.6540827	37.47618	1.308165	74.95236	3.795778	.2626309
6	1.2	3.5	5	.2857143	1.714286	3.285714	4.285714	.6540827	37.47618	1.308165	74.95236	4.554934	.2626309
7	1.2	3.5	5.833333	.2857143	2	3.833333	5	.6540827	37.47618	1.308165	74.95236	5.314089	.2626309
8	1.2	3.5	6.666667	.2857143	2.285714	4.380952	5.714286	.6540827	37.47618	1.308165	74.95236	6.073245	.2626309
CASE SEVENTEEN: CROWN HEIGHT RATIO 1:1.4, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5													
1	1.4	3.5	.7142857	.2857143	.2857143	.4285714	.7142857	.5404195	30.96376	1.080839	61.92751	.5798319	.4899573
2	1.4	3.5	1.428571	.2857143	.5714286	.8571429	1.428571	.5404195	30.96376	1.080839	61.92751	1.159664	.4899573
3	1.4	3.5	2.142857	.2857143	.8571429	1.285714	2.142857	.5404195	30.96376	1.080839	61.92751	1.739496	.4899573
4	1.4	3.5	2.857143	.2857143	1.142857	1.714286	2.857143	.5404195	30.96376	1.080839	61.92751	2.319328	.4899573
5	1.4	3.5	3.571429	.2857143	1.428571	2.142857	3.571429	.5404195	30.96376	1.080839	61.92751	2.899160	.4899573
6	1.4	3.5	4.285714	.2857143	1.714286	2.571429	4.285714	.5404195	30.96376	1.080839	61.92751	3.478992	.4899573
7	1.4	3.5	5	.2857143	2	3	5	.5404195	30.96376	1.080839	61.92751	4.058824	.4899573
8	1.4	3.5	5.714286	.2857143	2.285714	3.428571	5.714286	.5404195	30.96376	1.080839	61.92751	4.638655	.4899573
CASE EIGHTEEN: CROWN HEIGHT RATIO 1:1.6, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5													
1	1.6	3.5	.625	.2857143	.2857143	.3392857	.7142857	.4434483	25.40772	.8868967	50.81544	.4444799	.6838997
2	1.6	3.5	1.25	.2857143	.5714286	.6785714	1.428571	.4434483	25.40772	.8868967	50.81544	.8889597	.6838997
3	1.6	3.5	1.875	.2857143	.8571429	1.017857	2.142857	.4434483	25.40772	.8868967	50.81544	1.333440	.6838997
4	1.6	3.5	2.5	.2857143	1.142857	1.357143	2.857143	.4434483	25.40772	.8868967	50.81544	1.777919	.6838997
5	1.6	3.5	3.125	.2857143	1.428571	1.696429	3.571429	.4434483	25.40772	.8868967	50.81544	2.222399	.6838997
6	1.6	3.5	3.75	.2857143	1.714286	2.035714	4.285714	.4434483	25.40772	.8868967	50.81544	2.666879	.6838997
7	1.6	3.5	4.375	.2857143	2	2.375	5	.4434483	25.40772	.8868967	50.81544	3.111359	.6838997
8	1.6	3.5	5	.2857143	2.285714	2.714286	5.714286	.4434483	25.40772	.8868967	50.81544	3.555839	.6838997
CASE NINETEEN: CROWN HEIGHT RATIO 1:1.8, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5													
1	1.8	3.5	.5555556	.2857143	.2857143	.2698413	.7142857	.3612038	20.69545	.7224075	41.39090	.3412081	.8483888
2	1.8	3.5	1.111111	.2857143	.5714286	.5396825	1.428571	.3612038	20.69545	.7224075	41.39090	.6824162	.8483888
3	1.8	3.5	1.666667	.2857143	.8571429	.8095238	2.142857	.3612038	20.69545	.7224075	41.39090	1.023624	.8483888
4	1.8	3.5	2.222222	.2857143	1.142857	1.079365	2.857143	.3612038	20.69545	.7224075	41.39090	1.364832	.8483888
5	1.8	3.5	2.777778	.2857143	1.428571	1.349206	3.571429	.3612038	20.69545	.7224075	41.39090	1.706041	.8483888
6	1.8	3.5	3.333333	.2857143	1.714286	1.619048	4.285714	.3612038	20.69545	.7224075	41.39090	2.047249	.8483888
7	1.8	3.5	3.888889	.2857143	2	1.888889	5	.3612038	20.69545	.7224075	41.39090	2.388457	.8483888
8	1.8	3.5	4.444444	.2857143	2.285714	2.158730	5.714286	.3612038	20.69545	.7224075	41.39090	2.729665	.8483888
CASE TWENTY: CROWN HEIGHT RATIO 1:2.0, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5													
1	2	3.5	.5	.2857143	.2857143	.2142857	.7142857	.2914568	16.69924	.5829136	33.39849	.2614679	.9878827
2	2	3.5	1	.2857143	.5714286	.4285714	1.428571	.2914568	16.69924	.5829136	33.39849	.5229358	.9878827
3	2	3.5	1.5	.2857143	.8571429	.6428571	2.142857	.2914568	16.69924	.5829136	33.39849	.7844037	.9878827
4	2	3.5	2	.2857143	1.142857	.8571429	2.857143	.2914568	16.69924	.5829136	33.39849	1.045872	.9878827
5	2	3.5	2.5	.2857143	1.428571	1.071429	3.571429	.2914568	16.69924	.5829136	33.39849	1.307339	.9878827
6	2	3.5	3	.2857143	1.714286	1.285714	4.285714	.2914568	16.69924	.5829136	33.39849	1.568807	.9878827
7	2	3.5	3.5	.2857143	2	1.5	5	.2914568	16.69924	.5829136	33.39849	1.830275	.9878827
8	2	3.5	4	.2857143	2.285714	1.714286	5.714286	.2914568	16.69924	.5829136	33.39849	2.091743	.9878827
CASE TWENTY ONE: CROWN HEIGHT RATIO 1:2.2, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5													
1	2.2	3.5	.4545455	.2857143	.2857143	.1688312	.7142857	.2321038	13.29857	.4642077	26.59714	.1990664	1.106589
2	2.2	3.5	.9090909	.2857143	.5714286	.3376623	1.428571	.2321038	13.29857	.4642077	26.59714	.3981329	1.106589
3	2.2	3.5	1.363636	.2857143	.8571429	.5064935	2.142857	.2321038	13.29857	.4642077	26.59714	.5971993	1.106589
4	2.2	3.5	1.818182	.2857143	1.142857	.6753247	2.857143	.2321038	13.29857	.4642077	26.59714	.7962657	1.106589
5	2.2	3.5	2.272727	.2857143	1.428571	.8441558	3.571429	.2321038	13.29857	.4642077	26.59714	.9953322	1.106589
6	2.2	3.5	2.727273	.2857143	1.714286	1.012987	4.285714	.2321038	13.29857	.4642077	26.59714	1.194399	1.106589
7	2.2	3.5	3.181818	.2857143	2	1.181818	5	.2321038	13.29857	.4642077	26.59714	1.393465	1.106589
8	2.2	3.5	3.636364	.2857143	2.285714	1.350649	5.714286	.2321038	13.29857	.4642077	26.59714	1.592531	1.106589

Part 3 (continued)

July 17, 1990

Calculate Torospherical Shape Dimensions to Match a Given Set of Input Dimensions.

theta	crown radius R	crown volume Vc	flange volume Vf	volume end bell Ve	volume buoy Vb	---------parameters to derive C.G. of section--- l1	c1	d1	s1	l2	c2	d2	s2
degrees	calc ft	calc cu ft	calc cu ft	calc cu ft	calc cu ft	ft	ft	ft	ft	ft	ft	ft	ft
CASE FIFTEEN: CROWN HEIGHT RATIO 1:1.0, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5													
3.82e-14	1	2.094395	0	2.094395	4.188790	1.570796	1.414214	.9003163	.6366198	1.90e-16	0	0	.7142857
3.82e-14	2	16.75516	0	16.75516	33.51032	3.141593	2.828427	1.800633	1.273240	3.81e-16	0	0	1.428571
3.82e-14	3	56.54867	0	56.54867	113.0973	4.712389	4.242641	2.700949	1.909859	5.71e-16	0	0	2.142857
3.82e-14	4	134.0413	0	134.0413	268.0826	6.283185	5.656854	3.601265	2.546479	7.61e-16	0	0	2.857143
3.82e-14	5	261.7994	0	261.7994	523.5988	7.853982	7.071068	4.501582	3.183099	9.52e-16	0	0	3.571429
3.82e-14	6	452.3893	0	452.3893	904.7787	9.424778	8.485281	5.401898	3.819719	1.14e-15	0	0	4.285714
3.82e-14	7	718.3775	0	718.3775	1436.755	10.99557	9.899495	6.302214	4.456338	1.33e-15	0	0	5
3.82e-14	8	1072.330	0	1072.330	2144.661	12.56637	11.31371	7.202531	5.092958	1.52e-15	0	0	5.714286
CASE SIXTEEN: CROWN HEIGHT RATIO 1:1.2, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5 (continued)													
15.04764	1.025362	1.398310	.2326088	1.630919	3.261837	1.341344	1.247726	.9537980	.5803208	.0750374	.0748219	.2848939	.9967268
15.04764	2.050725	11.18648	1.860871	13.04735	26.09470	2.682687	2.495451	1.907596	1.160642	.1500748	.1496439	.5697877	1.993454
15.04764	4.101449	89.49182	14.88697	104.3788	208.7576	5.365374	4.990902	3.815192	2.321283	.3001496	.2992877	1.139575	3.986907
15.04764	5.126812	174.7887	29.07611	203.8648	407.7296	6.706718	6.238628	4.768990	2.901604	.3751870	.3741096	1.424469	4.983634
15.04764	6.152174	302.0349	50.24351	352.2784	704.5568	8.048061	7.486353	5.722788	3.481925	.4502244	.4489316	1.709363	5.980361
15.04764	7.177536	479.6202	79.78484	559.4051	1118.810	9.389405	8.734079	6.676586	4.062245	.5252618	.5237535	1.994257	6.977088
15.04764	8.202899	715.9346	119.0957	835.0303	1670.061	10.73075	9.981804	7.630384	4.642566	.6002991	.5985754	2.279151	7.973814
CASE SEVENTEEN: CROWN HEIGHT RATIO 1:1.4, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5 (continued)													
28.07249	1.095238	.9526685	.4198537	1.372522	2.745044	1.183776	1.126991	1.042700	.5364647	.1399878	.1385918	.2828650	.9887051
28.07249	2.190476	7.621348	3.358829	10.98018	21.96035	2.367552	2.253981	2.085400	1.072929	.2799756	.2771836	.5657300	1.977410
28.07249	3.285714	25.72205	11.33605	37.05810	74.11619	3.551328	3.380972	3.128100	1.609394	.4199634	.4157754	.8485950	2.966115
28.07249	4.380952	60.97078	26.87063	87.84142	175.6828	4.735104	4.507963	4.170800	2.145859	.5599512	.5543671	1.131460	3.954820
28.07249	5.476190	119.0836	52.48171	171.5653	343.1305	5.918880	5.634954	5.213499	2.682323	.6999390	.6929589	1.414325	4.943525
28.07249	6.571429	205.7764	90.68839	296.4648	592.9296	7.102656	6.761944	6.256199	3.218788	.8399268	.8315507	1.697190	5.932231
28.07249	7.666667	326.7653	144.0098	470.7751	941.5502	8.286432	7.888935	7.298899	3.755253	.9799147	.9701425	1.980055	6.920936
28.07249	8.761905	487.7663	214.9651	702.7313	1405.463	9.470208	9.015926	8.341599	4.291717	1.119902	1.108734	2.262920	7.909641
CASE EIGHTEEN: CROWN HEIGHT RATIO 1:1.6, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5 (continued)													
39.18456	1.207237	.6573271	.5609604	1.218287	2.436575	1.070694	1.035946	1.168058	.5011631	.1953999	.1916141	.2801787	.9782428
39.18456	2.414474	5.258617	4.487683	9.746300	19.49260	2.141389	2.071893	2.336115	1.002326	.3907998	.3832282	.5603573	1.956486
39.18456	3.621711	17.74783	15.14593	32.89376	65.78752	3.212083	3.107839	3.504173	1.503489	.5861997	.5748423	.8405360	2.934728
39.18456	4.828947	42.06893	35.90147	77.97040	155.9408	4.282777	4.143786	4.672230	2.004652	.7815996	.7664564	1.120715	3.912971
39.18456	6.036184	82.16589	70.12005	152.2859	304.5719	5.353472	5.179732	5.840288	2.505815	.9769995	.9580705	1.400893	4.891214
39.18456	7.243421	141.9827	121.1674	263.1501	526.3002	6.424166	6.215678	7.008346	3.006978	1.172399	1.149685	1.681072	5.869457
39.18456	8.450658	225.4632	192.4094	417.8726	835.7452	7.494860	7.251625	8.176403	3.508141	1.367799	1.341299	1.961251	6.847699
39.18456	9.657895	336.5515	287.2117	623.7632	1247.526	8.565555	8.287571	9.344461	4.009305	1.563199	1.532913	2.241429	7.825942
CASE NINETEEN: CROWN HEIGHT RATIO 1:1.8, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5 (continued)													
48.60910	1.366013	.4580248	.6630794	1.121104	2.242208	.9868181	.9654996	1.336503	.4723208	.2423968	.2351924	.2772224	.9669381
48.60910	2.732026	3.664198	5.304635	8.968833	17.93767	1.973636	1.930999	2.673005	.9446416	.4847936	.4703848	.5544449	1.933876
48.60910	4.098039	12.36667	17.90314	30.26981	60.53963	2.960454	2.896499	4.009508	1.416962	.7271904	.7055772	.8316673	2.900814
48.60910	5.464052	29.31359	42.43708	71.75067	143.5013	3.947272	3.861998	5.346011	1.889283	.9695872	.9407697	1.108890	3.867752
48.60910	6.830065	57.25310	82.88493	140.1380	280.2760	4.934091	4.827498	6.682514	2.361604	1.211984	1.175962	1.386112	4.834690
48.60910	8.196078	98.93335	143.2252	242.1585	484.3170	5.920909	5.792998	8.019016	2.833925	1.454381	1.411154	1.663335	5.801629
48.60910	9.562092	157.1025	227.4362	384.5387	769.0775	6.907727	6.758497	9.355519	3.306246	1.696778	1.646347	1.940557	6.768567
48.60910	10.92810	234.5087	339.4967	574.0053	1148.011	7.894545	7.723997	10.69202	3.778567	1.939174	1.881539	2.217779	7.735505
CASE TWENTY: CROWN HEIGHT RATIO 1:2.0, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5 (continued)													
56.60151	1.583333	.3213436	.7351583	1.056502	2.113004	.9229465	.9099350	1.561012	.4485534	.2822522	.2709142	.2742372	.9557436
56.60151	3.166667	2.570749	5.881266	8.452015	16.90403	1.845893	1.819870	3.122024	.8971069	.5645044	.5418284	.5484744	1.911487
56.60151	4.75	8.676278	19.84927	28.52555	57.05110	2.768840	2.729805	4.683035	1.345660	.8467566	.8127426	.8227116	2.867231
56.60151	6.333333	20.56599	47.05013	67.61612	135.2322	3.691786	3.639740	6.244047	1.794214	1.129009	1.083657	1.096949	3.822975
56.60151	7.916667	40.16795	91.89478	132.0627	264.1255	4.614733	4.549675	7.805059	2.242767	1.411261	1.354571	1.371186	4.778718
56.60151	9.5	69.41022	158.7942	228.2044	456.4088	5.537679	5.459610	9.366071	2.691321	1.693513	1.625485	1.645423	5.734462
56.60151	11.08333	110.2209	252.1593	362.3801	724.7603	6.460626	6.369545	10.92708	3.139874	1.975765	1.896399	1.919660	6.690205
56.60151	12.66667	164.5279	376.4010	540.9290	1081.858	7.383572	7.279480	12.48809	3.588427	2.258018	2.167313	2.193898	7.645949
CASE TWENTY ONE: CROWN HEIGHT RATIO 1:2.2, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5 (continued)													
63.40286	1.881119	.2259259	.7851490	1.011075	2.022150	.8732298	.8654104	1.864274	.4288305	.3161682	.3002816	.2713580	.9451565
63.40286	3.762238	1.807407	6.281192	8.088599	16.17720	1.746460	1.730821	3.728549	.8576611	.6323364	.6005633	.5427159	1.890313
63.40286	5.643357	6.099998	21.19902	27.29902	54.59804	2.619689	2.596231	5.592823	1.286492	.9485046	.9008449	.8140739	2.835470
63.40286	7.524476	14.45926	50.24954	64.70879	129.4176	3.492919	3.461642	7.457097	1.715322	1.264673	1.201127	1.085432	3.780626
63.40286	9.405594	28.24073	98.14363	126.3844	252.7687	4.366149	4.327052	9.321372	2.144153	1.580841	1.501408	1.356790	4.725783
63.40286	11.28671	48.79999	169.5922	218.3922	436.7843	5.239379	5.192463	11.18565	2.572983	1.897009	1.801690	1.628148	5.670939
63.40286	13.16783	77.49257	269.3061	346.7987	693.5974	6.112609	6.057873	13.04992	3.001814	2.213177	2.101972	1.899506	6.616096
63.40286	15.04895	115.6740	401.9963	517.6703	1035.341	6.985839	6.923284	14.91419	3.430644	2.529345	2.402253	2.170864	7.561252

Part 3 (continued)

July 17, 1990

Calculate Torospherical Shape Dimensions to Match a Given Set of Input Dimensions.

C.G. radius x ft	surface area Head As sq ft	surface area Buoy Ab sq ft	operating depth d assign ft	working pressure p psi	material allowable stress Sa assign ksi	knuckle stress multipl'r m table	thick shell t inches	Buoy pressure vessel weight Wb pounds	Buoy thin shell weight Wt pounds	Total water displaced Dg cu ft	Net buoyancy pounds	Efficiency E %
CASE FIFTEEN: CROWN HEIGHT RATIO 1:1.0, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5												
.6366198	6.283185	12.56637	2000	892	24	1.41	.3075153	157.6655	64.08849	269.3392102	111.6737	41.46
1.273240	25.13274	50.26548	2000	892	24	1.41	.6150305	1261.324	256.3540	2154.713681	893.3896	41.46
1.909859	56.54867	113.0973	2000	892	24	1.41	.9225458	4256.969	576.7964	7272.158675	3015.190	41.46
2.546479	100.5310	201.0619	2000	892	24	1.41	1.230061	10090.59	1025.416	17237.70945	7147.117	41.46
3.183099	157.0796	314.1593	2000	892	24	1.41	1.537576	19708.19	1602.212	33667.40127	13959.21	41.46
3.819719	226.1947	452.3893	2000	892	24	1.41	1.845092	34055.75	2307.186	58177.26940	24121.52	41.46
4.456338	307.8761	615.7522	2000	892	24	1.41	2.152607	54079.27	3140.336	92383.34909	38304.08	41.46
5.092958	402.1239	804.2477	2000	892	24	1.41	2.460122	80724.74	4101.663	137901.6756	57176.93	41.46
CASE SIXTEEN: CROWN HEIGHT RATIO 1:1.2, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5 (continued)												
.6023812	5.360822	10.72164	2000	892	24	1.41	.3153146	137.9322	54.68038	209.7361263	71.80396	34.24
1.204762	21.44329	42.88658	2000	892	24	1.41	.6306291	1103.457	218.7215	1677.889010	574.4316	34.24
2.409525	85.77315	171.5463	2000	892	24	1.41	1.261258	8827.659	874.8861	13423.11208	4595.453	34.24
3.011906	134.0205	268.0411	2000	892	24	1.41	1.576573	17241.52	1367.010	26217.01579	8975.494	34.24
3.614287	192.9896	385.9792	2000	892	24	1.41	1.891887	29793.35	1968.494	45303.00328	15509.65	34.24
4.216669	262.6803	525.3606	2000	892	24	1.41	2.207202	47310.73	2679.339	71939.49132	24628.76	34.24
4.819050	343.0926	686.1852	2000	892	24	1.41	2.522517	70621.27	3499.545	107384.8967	36763.63	34.24
CASE SEVENTEEN: CROWN HEIGHT RATIO 1:1.4, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5 (continued)												
.5842890	4.859797	9.719594	2000	892	24	1.41	.3368024	133.5622	49.56993	176.5063447	42.94417	24.33
1.168578	19.43919	38.87837	2000	892	24	1.41	.6736049	1068.497	198.2797	1412.050758	343.5534	24.33
1.752867	43.73817	87.47634	2000	892	24	1.41	1.010407	3606.179	446.1293	4765.671307	1159.493	24.33
2.337156	77.75675	155.5135	2000	892	24	1.41	1.347210	8547.979	793.1188	11296.40606	2748.427	24.33
2.921445	121.4949	242.9898	2000	892	24	1.41	1.684012	16695.27	1239.248	22063.29309	5368.021	24.33
3.505734	174.9527	349.9054	2000	892	24	1.41	2.020815	28849.43	1784.517	38125.37046	9275.941	24.33
4.090023	238.1300	476.2601	2000	892	24	1.41	2.357617	45811.83	2428.926	60541.67623	14729.85	24.33
4.674312	311.0270	622.0540	2000	892	24	1.41	2.694419	68383.83	3172.475	90371.24849	21987.41	24.33
CASE EIGHTEEN: CROWN HEIGHT RATIO 1:1.6, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5 (continued)												
.5747921	4.572532	9.145063	2000	892	24	1.41	.3712438	138.5179	46.63982	156.6717718	18.15383	11.59
1.149584	18.29013	36.58025	2000	892	24	1.41	.7424875	1108.144	186.5593	1253.374174	145.2306	11.59
1.724376	41.15278	82.30557	2000	892	24	1.41	1.113731	3739.984	419.7584	4230.137838	490.1534	11.59
2.299169	73.16051	146.3210	2000	892	24	1.41	1.484975	8865.148	746.2372	10026.99339	1161.845	11.59
2.873961	114.3133	228.6266	2000	892	24	1.41	1.856219	17314.74	1165.996	19583.97147	2269.229	11.59
3.448753	164.6111	329.2223	2000	892	24	1.41	2.227463	29919.88	1679.034	33841.10270	3921.227	11.59
4.023545	224.0540	448.1081	2000	892	24	1.41	2.598706	47511.65	2285.351	53738.41772	6226.764	11.59
4.598337	292.6420	585.2840	2000	892	24	1.41	2.969950	70921.19	2984.949	80215.94715	9294.761	11.59
CASE NINETEEN: CROWN HEIGHT RATIO 1:1.8, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5 (continued)												
.5698576	4.401230	8.802459	2000	892	24	1.41	.4200699	150.8640	44.89254	144.1739978	**-6.69003**	**-4.64**
1.139715	17.60492	35.20984	2000	892	24	1.41	.8401397	1206.912	179.5702	1153.391982	**-53.5203**	**-4.64**
1.709573	39.61107	79.22213	2000	892	24	1.41	1.260210	4073.329	404.0329	3892.697940	**-180.631**	**-4.64**
2.279430	70.41967	140.8393	2000	892	24	1.41	1.680279	9655.298	718.2807	9227.135859	**-428.162**	**-4.64**
2.849288	110.0307	220.0615	2000	892	24	1.41	2.100349	18858.00	1122.314	18021.74972	**-836.254**	**-4.64**
3.419145	158.4443	316.8885	2000	892	24	1.41	2.520419	32586.63	1616.131	31141.58352	**-1445.05**	**-4.64**
3.989003	215.6602	431.3205	2000	892	24	1.41	2.940489	51746.36	2199.735	49451.68124	**-2294.68**	**-4.64**
4.558861	281.6787	563.3574	2000	892	24	1.41	3.360559	77242.38	2873.123	73817.08687	**-3425.30**	**-4.64**
CASE TWENTY: CROWN HEIGHT RATIO 1:2.0, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5 (continued)												
.5673351	4.296138	8.592276	2000	892	24	1.41	.4868992	170.6897	43.82061	135.8661424	**-34.8236**	**-25.63**
1.134670	17.18455	34.36910	2000	892	24	1.41	.9737983	1365.518	175.2824	1086.929139	**-278.589**	**-25.63**
1.702005	38.66524	77.33048	2000	892	24	1.41	1.460697	4608.623	394.3855	3668.385846	**-940.237**	**-25.63**
2.269341	68.73821	137.4764	2000	892	24	1.41	1.947597	10924.14	701.1297	8695.433115	**-2228.71**	**-25.63**
2.836676	107.4034	214.8069	2000	892	24	1.41	2.434496	21336.22	1095.515	16983.26780	**-4352.95**	**-25.63**
3.404011	154.6610	309.3219	2000	892	24	1.41	2.921395	36868.98	1577.542	29347.08676	**-7521.90**	**-25.63**
3.971346	210.5108	421.0215	2000	892	24	1.41	3.408294	58546.58	2147.210	46602.08685	**-11944.5**	**-25.63**
4.538681	274.9528	549.9056	2000	892	24	1.41	3.895193	87393.14	2804.519	69563.46492	**-17829.7**	**-25.63**
CASE TWENTY: CROWN HEIGHT RATIO 1:2.0, FLANGE TO MAJOR AXIS RATO (W/r) = 3.5 (continued)												
.5660814	4.230444	8.460888	2000	892	24	1.41	.5784728	199.6912	43.15053	130.0242282	**-69.6670**	**-53.58**
1.132163	16.92178	33.84355	2000	892	24	1.41	1.156946	1597.530	172.6021	1040.193825	**-557.336**	**-53.58**
1.698244	38.07399	76.14799	2000	892	24	1.41	1.735418	5391.663	388.3547	3510.654160	**-1881.01**	**-53.58**
2.264325	67.68710	135.3742	2000	892	24	1.41	2.313891	12780.24	690.4084	8321.550602	**-4458.69**	**-53.58**
2.830407	105.7611	211.5222	2000	892	24	1.41	2.892364	24961.40	1078.763	16253.02852	**-8708.38**	**-53.58**
3.396488	152.2960	304.5920	2000	892	24	1.41	3.470837	43133.31	1553.419	28085.23328	**-15048.1**	**-53.58**
3.962570	207.2917	414.5835	2000	892	24	1.41	4.049309	68494.09	2114.376	44598.31026	**-23895.8**	**-53.58**
4.528651	270.7484	541.4968	2000	892	24	1.41	4.627782	102241.9	2761.634	66572.40482	**-35669.5**	**-53.58**

APPENDIX F

EXAMPLES OF CALCULATED DATA

FROM

"UNDER PRESSURE" PROGRAM

UTILITY MICROCOMPUTER PROGRAM "UNDER PRESSURE"

Specimen calculations have been made with this program for comparison with the results obtained in the previous appendices. The data output conveniently tabulates the pertinent information, including air weight, wet weight, pressure at failure, mode determination (thin or thick wall collapse), and material property review. Input data may be iterated to investigate a range of dimensions for comparison of failure mode and pressure. The only inconvenience for this application of buoy study is the need to input a material thickness and then calculate the failure pressure instead of the spreadsheet approach of establishing a required operating depth and calculating the corresponding required material thickness.

Study of the program output data showed some variation from spreadsheet calculations. One deviation in particular is the value used to represent pressure versus water depth. Our conversion factor used throughout the spreadsheet calculations was 0.446 psi per foot of water depth. This value is based upon an average density of seawater of 64.3 pound/foot^3, obtained from some obscure textbook years ago. The under pressure program, on the other hand produces calculated values corresponding with a conversion factor of 0.4492 psi/foot. Checking around, it turns out that you can get an argument on the topic, and several references give volume weights for seawater ranging between 64 (with no fractional part) to 69.7 pounds/foot^3. We decided not to pursue the point further, and stuck to tradition.

The specimen calculations include on the following pages:

a. Cylinder wall, with unspecified endcap, three examples

b. Flat plate endcap, edges fixed, five cases

c. Flat plate endcap, edges simply supported, two cases

d. Sphere, three cases.

TUBE CONFIGURATION
(External Pressure)

Inner Diameter: 31.2758 inches
Outer Diameter: 32.4648 inches
Wall Thickness: 0.5945 inches
Tube Length : 32.4648 inches
Weight in air : 547.45 lbs
Weight in water : -447.95 lbs

Failure mode: Thick wall crush
Collapse pressure 0.8629 Ksi (1920.8ft underwater)

Thin wall collapse at 2.9707 Ksi (6612.9 ft underwater)
Thin wall collapse mode : 4 nodes

HRstl-24ksi

Yield Stress	:	24.0000 Ksi
Poisson's ratio	:	0.2700
Density	:	0.2833 lb/cu in
Elastic Modulus	:	29.0000 Mpsi

Tube distortion values

Pressure (Ksi)	Depth (ft)	Stress (Ksi)	delta ID (inches)	delta OD (inches)	delta length (inches)
0.1000	222.6	2.6804	0.0025	0.0025	0.0007
0.2000	445.2	5.3609	0.0051	0.0051	0.0014
0.3000	667.8	8.0413	0.0076	0.0076	0.0021
0.4000	890.4	10.7217	0.0102	0.0102	0.0028
0.5000	1113.0	13.4021	0.0127	0.0127	0.0035
0.6000	1335.6	16.0826	0.0153	0.0153	0.0041
0.7000	1558.2	18.7630	0.0178	0.0178	0.0048
0.8000	1780.8	21.4434	0.0204	0.0204	0.0055
0.9000*	2003.4	24.1239	0.0229	0.0229	0.0062
1.0000*	2226.1	26.8043	0.0255	0.0255	0.0069
1.1000*	2448.7	29.4847	0.0280	0.0280	0.0076
1.2000*	2671.3	32.1651	0.0306	0.0306	0.0083
1.3000*	2893.9	34.8456	0.0331	0.0331	0.0090
1.4000*	3116.5	37.5260	0.0357	0.0357	0.0097
1.5000*	3339.1	40.2064	0.0382	0.0382	0.0104
1.6000*	3561.7	42.8869	0.0408	0.0408	0.0110
1.7000*	3784.3	45.5673	0.0433	0.0433	0.0117
1.8000*	4006.9	48.2477	0.0459	0.0459	0.0124
1.9000*	4229.5	50.9281	0.0484	0.0484	0.0131
2.0000*	4452.1	53.6086	0.0510	0.0510	0.0138

* = after housing failure

TUBE CONFIGURATION
(External Pressure)

```
Inner Diameter: 91.4520 inches
Outer Diameter: 94.9284 inches
Wall Thickness:  1.7382 inches
Tube Length    : 94.9284 inches
Weight in air :13685.55 lbs
Weight in water :-11200.10 lbs

Failure mode: Thick wall crush
Collapse pressure  0.8628 Ksi (1920.7ft underwater)

Thin wall collapse at   2.9701 Ksi (6611.5 ft underwater)
Thin wall collapse mode :    4 nodes

HRstl-24ksi
            Yield Stress       :    24.0000 Ksi
            Poisson's ratio    :     0.2700
            Density            :     0.2833 lb/cu in
            Elastic Modulus    :    29.0000 Mpsi
```

Tube distortion values

Pressure (Ksi)	Depth (ft)	Stress (Ksi)	delta ID (inches)	delta OD (inches)	delta length (inches)
0.1000	222.6	2.6807	0.0075	0.0075	0.0020
0.2000	445.2	5.3613	0.0149	0.0149	0.0040
0.3000	667.8	8.0420	0.0224	0.0224	0.0061
0.4000	890.4	10.7226	0.0298	0.0298	0.0081
0.5000	1113.0	13.4033	0.0373	0.0373	0.0101
0.6000	1335.6	16.0839	0.0447	0.0447	0.0121
0.7000	1558.2	18.7646	0.0522	0.0522	0.0141
0.8000	1780.8	21.4452	0.0596	0.0596	0.0161
0.9000*	2003.4	24.1259	0.0671	0.0671	0.0182
1.0000*	2226.1	26.8065	0.0745	0.0745	0.0202
1.1000*	2448.7	29.4872	0.0820	0.0820	0.0222
1.2000*	2671.3	32.1678	0.0894	0.0894	0.0242
1.3000*	2893.9	34.8485	0.0969	0.0969	0.0262
1.4000*	3116.5	37.5291	0.1043	0.1043	0.0283
1.5000*	3339.1	40.2098	0.1118	0.1118	0.0303
1.6000*	3561.7	42.8904	0.1192	0.1192	0.0323
1.7000*	3784.3	45.5711	0.1267	0.1267	0.0343
1.8000*	4006.9	48.2517	0.1341	0.1341	0.0363
1.9000*	4229.5	50.9324	0.1416	0.1416	0.0383
2.0000*	4452.1	53.6130	0.1490	0.1490	0.0404

* = after housing failure

TUBE CONFIGURATION
(External Pressure)

Inner Diameter: 92.5000 inches
Outer Diameter: 96.0000 inches
Wall Thickness: 1.7500 inches
Tube Length : 95.0000 inches
Weight in air :13945.66 lbs
Weight in water :-11524.20 lbs

Failure mode: Thick wall crush
Collapse pressure 0.8590 Ksi (1912.3ft underwater)

Thin wall collapse at 2.9760 Ksi (6624.8 ft underwater)
Thin wall collapse mode : 4 nodes

HRstl-24ksi

Yield Stress	:	24.0000 Ksi
Poisson's ratio	:	0.2700
Density	:	0.2833 lb/cu in
Elastic Modulus	:	29.0000 Mpsi

Tube distortion values

Pressure (Ksi)	Depth (ft)	Stress (Ksi)	delta ID (inches)	delta OD (inches)	delta length (inches)
0.1000	222.6	2.6929	0.0076	0.0076	0.0020
0.2000	445.2	5.3857	0.0151	0.0151	0.0041
0.3000	667.8	8.0786	0.0227	0.0227	0.0061
0.4000	890.4	10.7714	0.0303	0.0303	0.0081
0.5000	1113.0	13.4643	0.0379	0.0379	0.0101
0.6000	1335.6	16.1571	0.0454	0.0454	0.0122
0.7000	1558.2	18.8500	0.0530	0.0530	0.0142
0.8000	1780.8	21.5429	0.0606	0.0606	0.0162
0.9000*	2003.4	24.2357	0.0681	0.0681	0.0183
1.0000*	2226.1	26.9286	0.0757	0.0757	0.0203
1.1000*	2448.7	29.6214	0.0833	0.0833	0.0223
1.2000*	2671.3	32.3143	0.0908	0.0908	0.0243
1.3000*	2893.9	35.0071	0.0984	0.0984	0.0264
1.4000*	3116.5	37.7000	0.1060	0.1060	0.0284
1.5000*	3339.1	40.3929	0.1136	0.1136	0.0304
1.6000*	3561.7	43.0857	0.1211	0.1211	0.0325
1.7000*	3784.3	45.7786	0.1287	0.1287	0.0345
1.8000*	4006.9	48.4714	0.1363	0.1363	0.0365
1.9000*	4229.5	51.1643	0.1438	0.1438	0.0385
2.0000*	4452.1	53.8571	0.1514	0.1514	0.0406

* = after housing failure

ENDCAP CONFIGURATION - Endcap Circular, Fixed

Free Diameter	: 31.8648 inches		
Outer Diameter	: 32.4648 inches		
Endcap Thickness	: 1.0000 inches		
Weight in air :	234.51 lbs	Weight in water :	203.85 lbs
Endcap failure at	0.1985 Ksi	(441.9 ft underwater)	

HRstl-24ksi

Yield Stress	: 24.0000 Ksi
Poisson's ratio	: 0.2700
Density	: 0.2833 lb/cu in
Elastic Modulus	: 29.0000 Mpsi

Endcap distortion values (* = after failure)

Pressure (Ksi)	Depth (ft)	Max.Stress (Ksi)	Max.Shear (Ksi)	Max.Seat (Ksi)	C.defln (inches)
0.1000	222.6	12.0892	0.7966	2.7306	-0.0386
0.2000*	445.2	24.1784	1.5932	5.4613	-0.0772
0.3000*	667.8	36.2676	2.3899	8.1919	-0.1159
0.4000*	890.4	48.3568	3.1865	10.9225	-0.1545
0.5000*	1113.0	60.4460	3.9831	13.6532	-0.1931
0.6000*	1335.6	72.5352	4.7797	16.3838	-0.2317
0.7000*	1558.2	84.6244	5.5763	19.1144	-0.2704
0.8000*	1780.8	96.7136	6.3730	21.8451	-0.3090
0.9000*	2003.4	108.8028	7.1696	24.5757	-0.3476
1.0000*	2226.1	120.8920	7.9662	27.3063	-0.3862
1.1000*	2448.7	132.9811	8.7628	30.0370	-0.4249
1.2000*	2671.3	145.0703	9.5594	32.7676	-0.4635
1.3000*	2893.9	157.1595	10.3561	35.4982	-0.5021
1.4000*	3116.5	169.2487	11.1527	38.2289	-0.5407
1.5000*	3339.1	181.3379	11.9493	40.9595	-0.5794
1.6000*	3561.7	193.4271	12.7459	43.6901	-0.6180
1.7000*	3784.3	205.5163	13.5425	46.4208	-0.6566
1.8000*	4006.9	217.6055	14.3392	49.1514	-0.6952
1.9000*	4229.5	229.6947	15.1358	51.8820	-0.7339
2.0000*	4452.1	241.7839	15.9324	54.6127	-0.7725

* = after housing failure

ENDCAP CONFIGURATION - Endcap Circular, Fixed

Free Diameter : 31.8648 inches
Outer Diameter : 32.4648 inches
Endcap Thickness : 2.1250 inches
Weight in air : 498.33 lbs Weight in water : 433.18 lbs
Endcap failure at 0.8965 Ksi (1995.6 ft underwater)

HRstl-24ksi
Yield Stress : 24.0000 Ksi
Poisson's ratio : 0.2700
Density : 0.2833 lb/cu in
Elastic Modulus : 29.0000 Mpsi

Endcap distortion values (* = after failure)

Pressure (Ksi)	Depth (ft)	Max.Stress (Ksi)	Max.Shear (Ksi)	Max.Seat (Ksi)	C.defln (inches)
0.1000	222.6	2.6772	0.3749	2.7306	-0.0040
0.2000	445.2	5.3544	0.7498	5.4613	-0.0081
0.3000	667.8	8.0316	1.1246	8.1919	-0.0121
0.4000	890.4	10.7088	1.4995	10.9225	-0.0161
0.5000	1113.0	13.3860	1.8744	13.6532	-0.0201
0.6000	1335.6	16.0632	2.2493	16.3838	-0.0242
0.7000	1558.2	18.7403	2.6242	19.1144	-0.0282
0.8000	1780.8	21.4175	2.9990	21.8451	-0.0322
0.9000*	2003.4	24.0947	3.3739	24.5757	-0.0362
1.0000*	2226.1	26.7719	3.7488	27.3063	-0.0403
1.1000*	2448.7	29.4491	4.1237	30.0370	-0.0443
1.2000*	2671.3	32.1263	4.4986	32.7676	-0.0483
1.3000*	2893.9	34.8035	4.8734	35.4982	-0.0523
1.4000*	3116.5	37.4807	5.2483	38.2289	-0.0564
1.5000*	3339.1	40.1579	5.6232	40.9595	-0.0604
1.6000*	3561.7	42.8351	5.9981	43.6901	-0.0644
1.7000*	3784.3	45.5123	6.3730	46.4208	-0.0684
1.8000*	4006.9	48.1895	6.7478	49.1514	-0.0725
1.9000*	4229.5	50.8666	7.1227	51.8820	-0.0765
2.0000*	4452.1	53.5438	7.4976	54.6127	-0.0805

* = after housing failure

ENDCAP CONFIGURATION - Endcap Circular, Fixed

```
Free Diameter                :  30.4648 inches
Outer Diameter               :  32.4648 inches
Endcap Thickness             :   2.1250 inches
Weight in air   :   498.33 lbs     Weight in water :   433.18 lbs
Endcap failure at   0.9807 Ksi    (2183.2 ft underwater)

HRstl-24ksi
             Yield Stress     :    24.0000 Ksi
             Poisson's ratio  :     0.2700
             Density          :     0.2833 lb/cu in
             Elastic Modulus  :    29.0000 Mpsi
```

Endcap distortion values (* = after failure)

Pressure (Ksi)	Depth (ft)	Max.Stress (Ksi)	Max.Shear (Ksi)	Max.Seat (Ksi)	C.defln (inches)
0.1000	222.6	2.4471	0.3584	0.8374	-0.0034
0.2000	445 2	4.8942	0.7168	1.6748	-0.0067
0.3000	667.8	7.3413	1.0752	2.5122	-0.0101
0.4000	890.4	9.7884	1.4336	3.3497	-0.0135
0.5000	1113.0	12.2356	1.7920	4.1871	-0.0168
0.6000	1335.6	14.6827	2.1505	5.0245	-0.0202
0.7000	1558.2	17.1298	2.5089	5.8619	-0.0235
0.8000	1780.8	19.5769	2.8673	6.6993	-0.0269
0.9000	2003.4	22.0240	3.2257	7.5367	-0.0303
1.0000*	2226.1	24.4711	3.5841	8.3741	-0.0336
1.1000*	2448.7	26.9182	3.9425	9.2116	-0.0370
1.2000*	2671.3	29.3653	4.3009	10.0490	-0.0404
1.3000*	2893.9	31.8125	4.6593	10.8864	-0.0437
1.4000*	3116.5	34.2596	5.0177	11.7238	-0.0471
1.5000*	3339.1	36.7067	5.3761	12.5612	-0.0504
1.6000*	3561.7	39.1538	5.7346	13.3986	-0.0538
1.7000*	3784.3	41.6009	6.0930	14.2360	-0.0572
1.8000*	4006.9	44.0480	6.4514	15.0735	-0.0605
1.9000*	4229.5	46.4951	6.8098	15.9109	-0.0639
2.0000*	4452.1	48.9422	7.1682	16.7483	-0.0673

* = after housing failure

ENDCAP CONFIGURATION - Endcap Circular, Fixed

Free Diameter : 30.4648 inches
Outer Diameter : 32.4648 inches
Endcap Thickness : 2.0000 inches
Weight in air : 469.02 lbs   Weight in water : 407.70 lbs
Endcap failure at 0.8688 Ksi (1933.9 ft underwater)

HRstl-24ksi

Yield Stress : 24.0000 Ksi
Poisson's ratio : 0.2700
Density : 0.2833 lb/cu in
Elastic Modulus : 29.0000 Mpsi

Endcap distortion values (* = after failure)

Pressure (Ksi)	Depth (ft)	Max.Stress (Ksi)	Max.Shear (Ksi)	Max.Seat (Ksi)	C.defln (inches)
0.1000	222.6	2.7626	0.3808	0.8374	-0.0040
0.2000	445.2	5.5251	0.7616	1.6748	-0.0081
0.300C	667.8	8.2877	1.1424	2.5122	-0.0121
0.4000	890.4	11.0502	1.5232	3.3497	-0.0161
0.5000	1113.0	13.8128	1.9040	4.1871	-0.0202
0.6000	1335.6	16.5754	2.2849	5.0245	-0.0242
0.7000	1558.2	19.3379	2.6657	5.8619	-0.0282
0.8000	1780.8	22.1005	3.0465	6.6993	-0.0323
0.9000*	2003.4	24.8630	3.4273	7.5367	-0.0363
1.0000*	2226.1	27.6256	3.8081	8.3741	-0.0403
1.1000*	2448.7	30.3882	4.1889	9.2116	-0.0444
1.2000*	2671.3	33.1507	4.5697	10.0490	-0.0484
1.3000*	2893.9	35.9133	4.9505	10.8864	-0.0524
1.4000*	3116.5	38.6758	5.3313	11.7238	-0.0565
1.5000*	3339.1	41.4384	5.7121	12.5612	-0.0605
1.6000*	3561.7	44.2010	6.0930	13.3986	-0.0645
1.7000*	3784.3	46.9635	6.4738	14.2360	-0.0686
1.8000*	4006.9	49.7261	6.8546	15.0735	-0.0726
1.9000*	4229.5	52.4886	7.2354	15.9109	-0.0766
2.0000*	4452.1	55.2512	7.6162	16.7483	-0.0807

* = after housing failure

ENDCAP CONFIGURATION - Endcap Circular, Fixed

Free Diameter : 65.6296 inches
Outer Diameter : 69.9400 inches
Endcap Thickness : 2.1550 inches
Weight in air : 2345.50 lbs Weight in water : 2038.83 lbs
Endcap failure at 0.2173 Ksi (483.8 ft underwater)

HRstl-24ksi

Yield Stress	:	24.0000 Ksi
Poisson's ratio	:	0.2700
Density	:	0.2833 lb/cu in
Elastic Modulus	:	29.0000 Mpsi

Endcap distortion values (* = after failure)

Pressure (Ksi)	Depth (ft)	Max.Stress (Ksi)	Max.Shear (Ksi)	Max.Seat (Ksi)	C.defln (inches)
0.1000	222.6	11.0428	0.7614	0.8371	-0.0694
0.2000	445.2	22.0856	1.5227	1.6742	-0.1389
0.3000*	667.8	33.1285	2.2841	2.5113	-0.2083
0.4000*	890.4	44.1713	3.0455	3.3484	-0.2778
0.5000*	1113.0	55.2141	3.8068	4.1854	-0.3472
0.6000*	1335.6	66.2569	4.5682	5.0225	-0.4167
0.7000*	1558.2	77.2997	5.3295	5.8596	-0.4861
0.8000*	1780.8	88.3426	6.0909	6.6967	-0.5556
0.9000*	2003.4	99.3854	6.8523	7.5338	-0.6250
1.0000*	2226.1	110.4282	7.6136	8.3709	-0.6945
1.1000*	2448.7	121.4710	8.3750	9.2080	-0.7639
1.2000*	2671.3	132.5138	9.1364	10.0451	-0.8334
1.3000*	2893.9	143.5567	9.8977	10.8822	-0.9028
1.4000*	3116.5	154.5995	10.6591	11.7192	-0.9723
1.5000*	3339.1	165.6423	11.4205	12.5563	-1.0417
1.6000*	3561.7	176.6851	12.1818	13.3934	-1.1112
1.7000*	3784.3	187.7279	12.9432	14.2305	-1.1806
1.8000*	4006.9	198.7707	13.7046	15.0676	-1.2501
1.9000*	4229.5	209.8136	14.4659	15.9047	-1.3195
2.0000*	4452.1	220.8564	15.2273	16.7418	-1.3890

* = after housing failure

ENDCAP CONFIGURATION - Endcap Circular, Simply Supported

```
Free Diameter                : 65.6296 inches
Outer Diameter               : 69.9400 inches
Endcap Thickness             :  4.3750 inches
Weight in air   :  4761.74 lbs     Weight in water :  4139.16 lbs
Endcap failure at   0.3479 Ksi    (774.4 ft underwater)

HRstl-24ksi
            Yield Stress     :    24.0000 Ksi
            Poisson's ratio  :     0.2700
            Density          :     0.2833 lb/cu in
            Elastic Modulus  :    29.0000 Mpsi
```

Endcap distortion values (* = after failure)

Pressure (Ksi)	Depth (ft)	Max.Stress (Ksi)	Max.Shear (Ksi)	Max.Seat (Ksi)	C.defln (inches)
0.1000	222.6	6.8986	0.3750	0.8371	-0.0344
0.2000	445.2	13.7972	0.7501	1.6742	-0.0689
0.3000	667.8	20.6959	1.1251	2.5113	-0.1033
0.4000*	890.4	27.5945	1.5001	3.3484	-0.1378
0.5000*	1113.0	34.4931	1.8751	4.1854	-0.1722
0.6000*	1335.6	41.3917	2.2502	5.0225	-0.2066
0.7000*	1558.2	48.2904	2.6252	5.8596	-0.2411
0.8000*	1780.8	55.1890	3.0002	6.6967	-0.2755
0.9000*	2003.4	62.0876	3.3752	7.5338	-0.3100
1.0000*	2226.1	68.9862	3.7503	8.3709	-0.3444
1.1000*	2448.7	75.8849	4.1253	9.2080	-0.3789
1.2000*	2671.3	82.7835	4.5003	10.0451	-0.4133
1.3000*	2893.9	89.6821	4.8753	10.8822	-0.4477
1.4000*	3116.5	96.5807	5.2504	11.7192	-0.4822
1.5000*	3339.1	103.4793	5.6254	12.5563	-0.5166
1.6000*	3561.7	110.3780	6.0004	13.3934	-0.5511
1.7000*	3784.3	117.2766	6.3754	14.2305	-0.5855
1.8000*	4006.9	124.1752	6.7505	15.0676	-0.6199
1.9000*	4229.5	131.0738	7.1255	15.9047	-0.6544
2.0000*	4452.1	137.9725	7.5005	16.7418	-0.6888

* = after housing failure

ENDCAP CONFIGURATION - Endcap Circular, Simply Supported

```
Free Diameter                 :  65.6296 inches
Outer Diameter                :  69.9400 inches
Endcap Thickness              :   7.0000 inches
Weight in air   :  7618.78 lbs     Weight in water :  6622.66 lbs
Endcap failure at   0.8906 Ksi    (1982.6 ft underwater)

HRstl-24ksi
            Yield Stress      :    24.0000 Ksi
            Poisson's ratio   :     0.2700
            Density           :     0.2833 lb/cu in
            Elastic Modulus   :    29.0000 Mpsi
```

Endcap distortion values (* = after failure)

Pressure (Ksi)	Depth (ft)	Max.Stress (Ksi)	Max.Shear (Ksi)	Max.Seat (Ksi)	C.defln (inches)
0.1000	222.6	2.6948	0.2344	0.8371	-0.0084
0.2000	445.2	5.3895	0.4688	1.6742	-0.0168
0.3000	667.8	8.0843	0.7032	2.5113	-0.0252
0.4000	890.4	10.7791	0.9376	3.3484	-0.0336
0.5000	1113.0	13.4739	1.1720	4.1854	-0.0420
0.6000	1335.6	16.1686	1.4063	5.0225	-0.0505
0.7000	1558.2	18.8634	1.6407	5.8596	-0.0589
0.8000	1780.8	21.5582	1.8751	6.6967	-0.0673
0.9000*	2003.4	24.2530	2.1095	7.5338	-0.0757
1.0000*	2226.1	26.9477	2.3439	8.3709	-0.0841
1.1000*	2448.7	29.6425	2.5783	9.2080	-0.0925
1.2000*	2671.3	32.3373	2.8127	10.0451	-0.1009
1.3000*	2893.9	35.0321	3.0471	10.8822	-0.1093
1.4000*	3116.5	37.7268	3.2815	11.7192	-0.1177
1.5000*	3339.1	40.4216	3.5159	12.5563	-0.1261
1.6000*	3561.7	43.1164	3.7503	13.3934	-0.1345
1.7000*	3784.3	45.8112	3.9847	14.2305	-0.1429
1.8000*	4006.9	48.5059	4.2190	15.0676	-0.1514
1.9000*	4229.5	51.2007	4.4534	15.9047	-0.1598
2.0000*	4452.1	53.8955	4.6878	16.7418	-0.1682

* = after housing failure

SPHERE CONFIGURATION
(External Pressure)

```
Inner Diameter  :  61.8000 inches
Outer Diameter  :  63.0000 inches
Wall Thickness  :   0.6000 inches

Weight in air   :  2079.36 lbs
Weight in water : -2770.07 lbs
Hemisphere collapse at    0.8970 Ksi     (1996.7 ft underwater)
Thin wall collapse at  :   3.9146 Ksi
Thick wall collapse at :   0.8970 Ksi

HRstl-24ksi
            Yield Stress      :    24.0000 Ksi
            Poisson's ratio   :     0.2700
            Density           :     0.2833 lb/cu in
            Elastic Modulus   :    29.0000 Mpsi
```

Sphere distortion values

Pressure (Ksi)	Depth (ft)	Stress (Ksi)	delta ID (inches)	delta OD (inches)	seat (Ksi)
0.1000	222.6	2.6000	0.0041	0.0041	2.6502
0.2000	445.2	5.2000	0.0082	0.0082	5.3005
0.3000	667.8	7.8000	0.0123	0.0123	7.9507
0.4000	890.4	10.4000	0.0163	0.0163	10.6010
0.5000	1113.0	13.0000	0.0204	0.0204	13.2512
0.6000	1335.6	15.6000	0.0245	0.0245	15.9014
0.7000	1558.2	18.2000	0.0286	0.0286	18.5517
0.8000	1780.8	20.8000	0.0327	0.0327	21.2019
0.9000*	2003.4	23.4000	0.0368	0.0368	23.8522
1.0000*	2226.1	26.0000	0.0408	0.0408	26.5024
1.1000*	2448.7	28.6000	0.0449	0.0449	29.1526
1.2000*	2671.3	31.2000	0.0490	0.0490	31.8029
1.3000*	2893.9	33.8000	0.0531	0.0531	34.4531
1.4000*	3116.5	36.4000	0.0572	0.0572	37.1034
1.5000*	3339.1	39.0000	0.0613	0.0613	39.7536
1.6000*	3561.7	41.6000	0.0653	0.0653	42.4038
1.7000*	3784.3	44.2000	0.0694	0.0694	45.0541
1.8000*	4006.9	46.8000	0.0735	0.0735	47.7043
1.9000*	4229.5	49.4000	0.0776	0.0776	50.3546
2.0000*	4452.1	52.0000	0.0817	0.0817	53.0048

* = after housing failure

SPHERE CONFIGURATION
(External Pressure)

Inner Diameter : 61.7500 inches
Outer Diameter : 63.0000 inches
Wall Thickness : 0.6250 inches

Weight in air : 2164.27 lbs
Weight in water : -2685.16 lbs
Hemisphere collapse at 0.9336 Ksi (2078.3 ft underwater)
Thin wall collapse at : 4.2510 Ksi
Thick wall collapse at : 0.9336 Ksi

HRstl-24ksi

Yield Stress : 24.0000 Ksi
Poisson's ratio : 0.2700
Density : 0.2833 lb/cu in
Elastic Modulus : 29.0000 Mpsi

Sphere distortion values

Pressure (Ksi)	Depth (ft)	Stress (Ksi)	delta ID (inches)	delta OD (inches)	seat (Ksi)
0.1000	222.6	2.4950	0.0039	0.0039	2.5453
0.2000	445.2	4.9900	0.0078	0.0078	5.0905
0.3000	667.8	7.4850	0.0118	0.0118	7.6358
0.4000	890.4	9.9800	0.0157	0.0157	10.1810
0.5000	1113.0	12.4750	0.0196	0.0196	12.7263
0.6000	1335.6	14.9700	0.0235	0.0235	15.2715
0.7000	1558.2	17.4650	0.0274	0.0274	17.8168
0.8000	1780.8	19.9600	0.0313	0.0313	20.3620
0.9000	2003.4	22.4550	0.0353	0.0353	22.9073
1.0000*	2226.1	24.9500	0.0392	0.0392	25.4525
1.1000*	2448.7	27.4450	0.0431	0.0431	27.9978
1.2000*	2671.3	29.9400	0.0470	0.0470	30.5430
1.3000*	2893.9	32.4350	0.0509	0.0509	33.0883
1.4000*	3116.5	34.9300	0.0548	0.0548	35.6335
1.5000*	3339.1	37.4250	0.0588	0.0588	38.1788
1.6000*	3561.7	39.9200	0.0627	0.0627	40.7240
1.7000*	3784.3	42.4150	0.0666	0.0666	43.2693
1.8000*	4006.9	44.9100	0.0705	0.0705	45.8145
1.9000*	4229.5	47.4050	0.0744	0.0744	48.3598
2.0000*	4452.1	49.9000	0.0783	0.0783	50.9050

* = after housing failure

SPHERE CONFIGURATION
(External Pressure)

```
Inner Diameter   : 106.0000 inches
Outer Diameter   : 108.0000 inches
Wall Thickness   :   1.0000 inches

Weight in air    : 10190.05 lbs
Weight in water  : -14240.91 lbs
Hemisphere collapse at    0.8725 Ksi     (1942.3 ft underwater)
Thin wall collapse at  :   3.6981 Ksi
Thick wall collapse at :   0.8725 Ksi

HRstl-24ksi
            Yield Stress      :   24.0000 Ksi
            Poisson's ratio   :    0.2700
            Density           :    0.2833 lb/cu in
            Elastic Modulus   :   29.0000 Mpsi
```

Sphere distortion values

Pressure (Ksi)	Depth (ft)	Stress (Ksi)	delta ID (inches)	delta OD (inches)	seat (Ksi)
0.1000	222.6	2.6750	0.0072	0.0072	2.7252
0.2000	445.2	5.3500	0.0144	0.0144	5.4505
0.3000	667.8	8.0250	0.0216	0.0216	8.1757
0.4000	890.4	10.7000	0.0288	0.0288	10.9009
0.5000	1113.0	13.3750	0.0360	0.0360	13.6262
0.6000	1335.6	16.0500	0.0432	0.0432	16.3514
0.7000	1558.2	18.7250	0.0504	0.0504	19.0766
0.8000	1780.8	21.4000	0.0576	0.0576	21.8019
0.9000*	2003.4	24.0750	0.0648	0.0648	24.5271
1.0000*	2226.1	26.7500	0.0720	0.0720	27.2523
1.1000*	2448.7	29.4250	0.0793	0.0793	29.9776
1.2000*	2671.3	32.1000	0.0865	0.0865	32.7028
1.3000*	2893.9	34.7750	0.0937	0.0937	35.4280
1.4000*	3116.5	37.4500	0.1009	0.1009	38.1533
1.5000*	3339.1	40.1250	0.1081	0.1081	40.8785
1.6000*	3561.7	42.8000	0.1153	0.1153	43.6037
1.7000*	3784.3	45.4750	0.1225	0.1225	46.3290
1.8000*	4006.9	48.1500	0.1297	0.1297	49.0542
1.9000*	4229.5	50.8250	0.1369	0.1369	51.7794
2.0000*	4452.1	53.5000	0.1441	0.1441	54.5047

* = after housing failure

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This is a review of the possible methods of constructing an apex buoy to be deployed as subsurface support for underwater pyramidal arrays. Several categories of buoy construction are presented, with an investigation of the mathematical expressions necessary to derive shape, size, weight, and net buoyancy. Selection of nominal probable buoy sizes based on studies done by others using the Navy-owned computer program "D-CEL" was made in the report development. Some cost data are summarized for buoyancy materials and devices available from commercial sources. Appendixes include spreadsheet calculations for various buoy shapes that lend themselves to construction as metal shell voids capable of operating at the selected water depth.

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